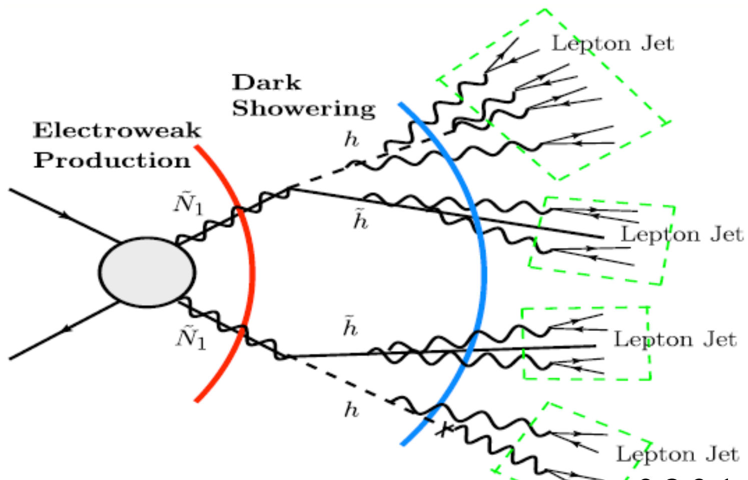
Hunting for Lepton Jets

Itay Yavin

New York University

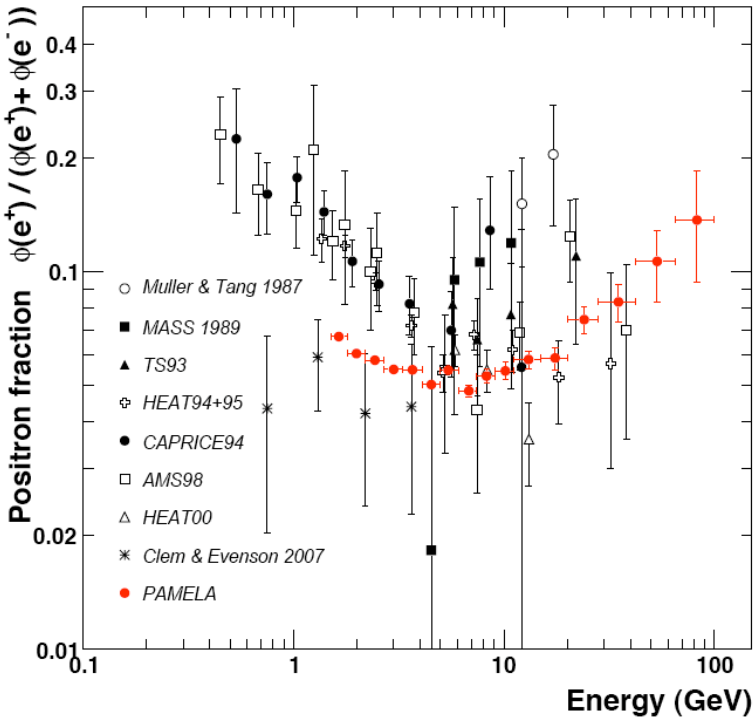


M. Baumgart, C. Cheung, J. T. Ruderman, L. T. Wang and I. Y. 0901.0283 [hep-ph]

C. Cheung, J. T. Ruderman, L. T. Wang and I. Y. 0909.0290[hep-ph]

Part I

Introduction



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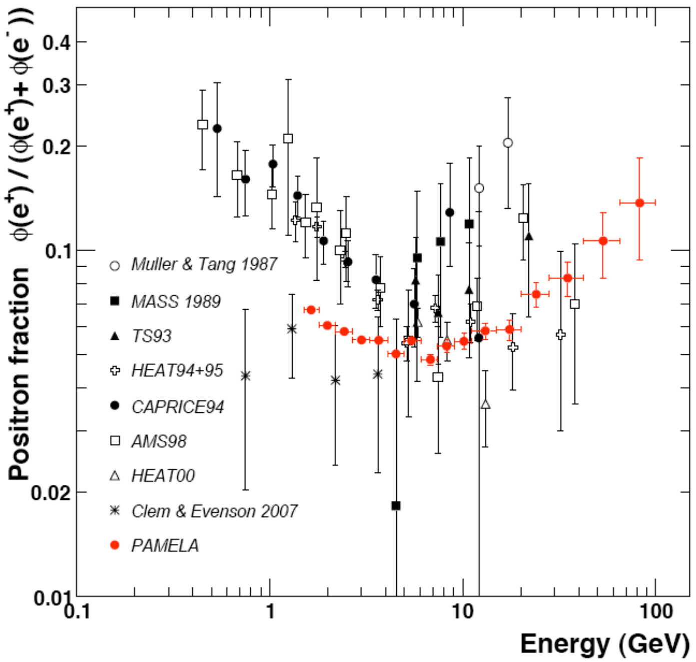

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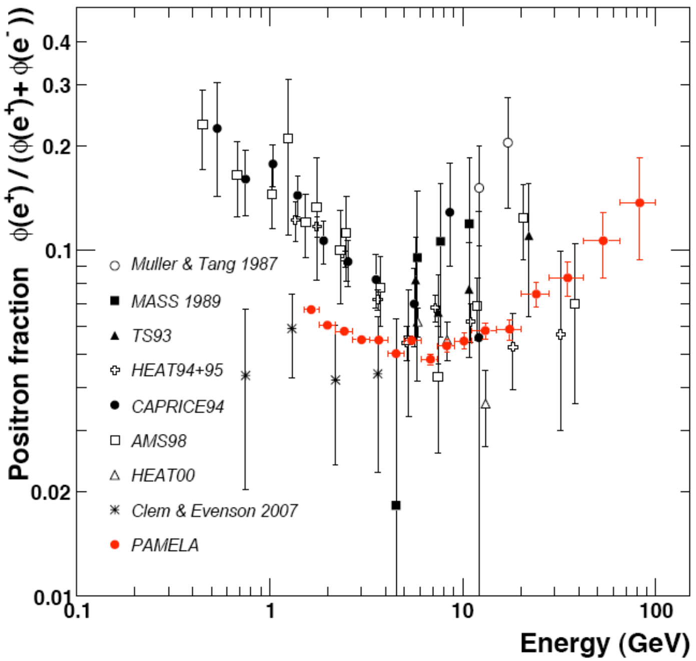

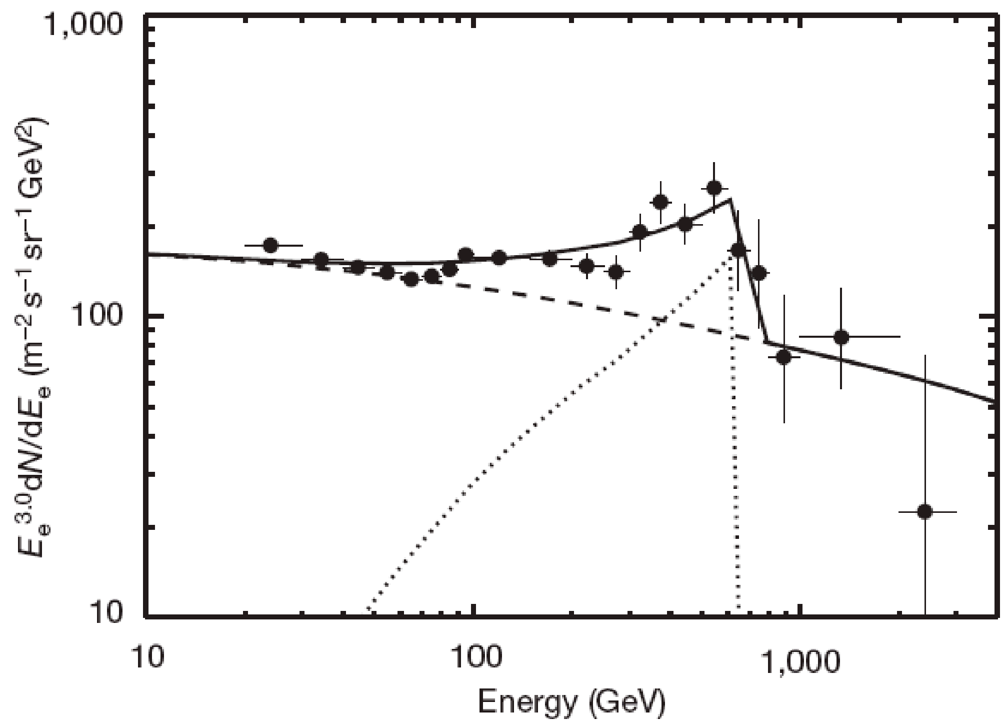

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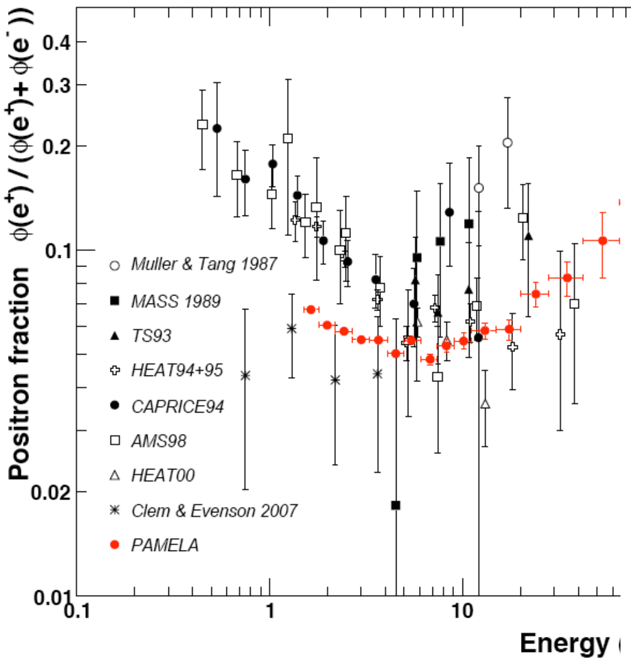

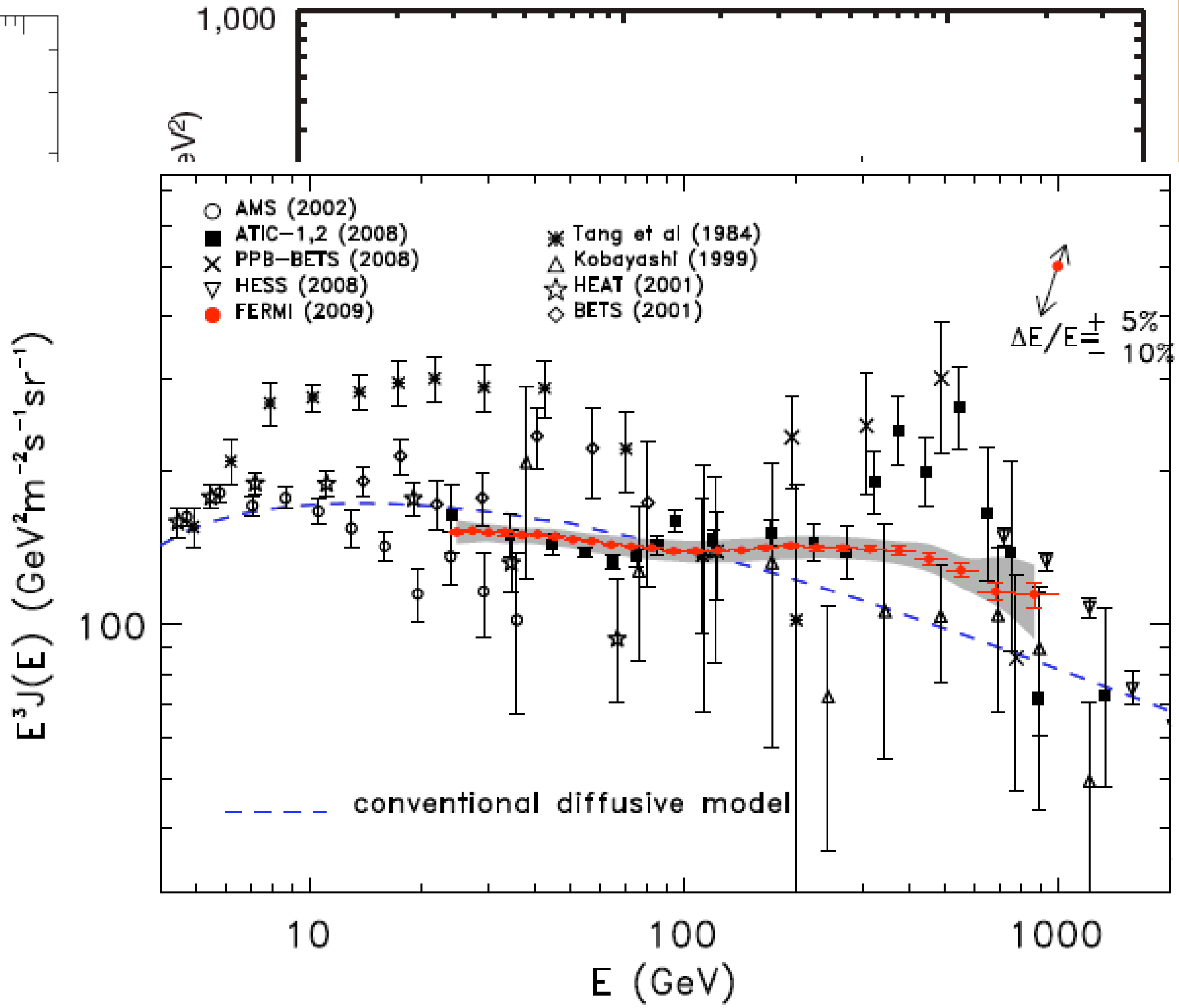

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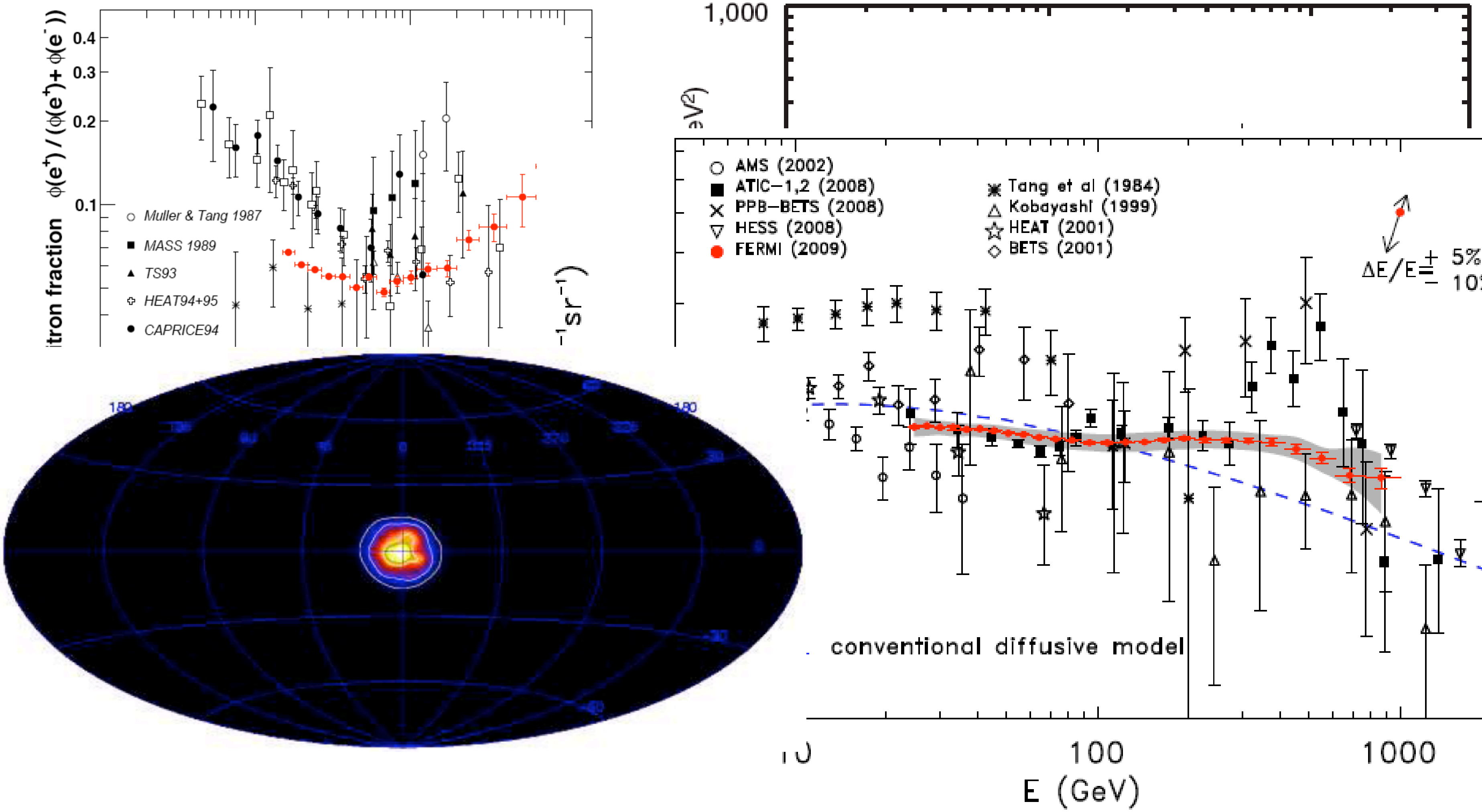

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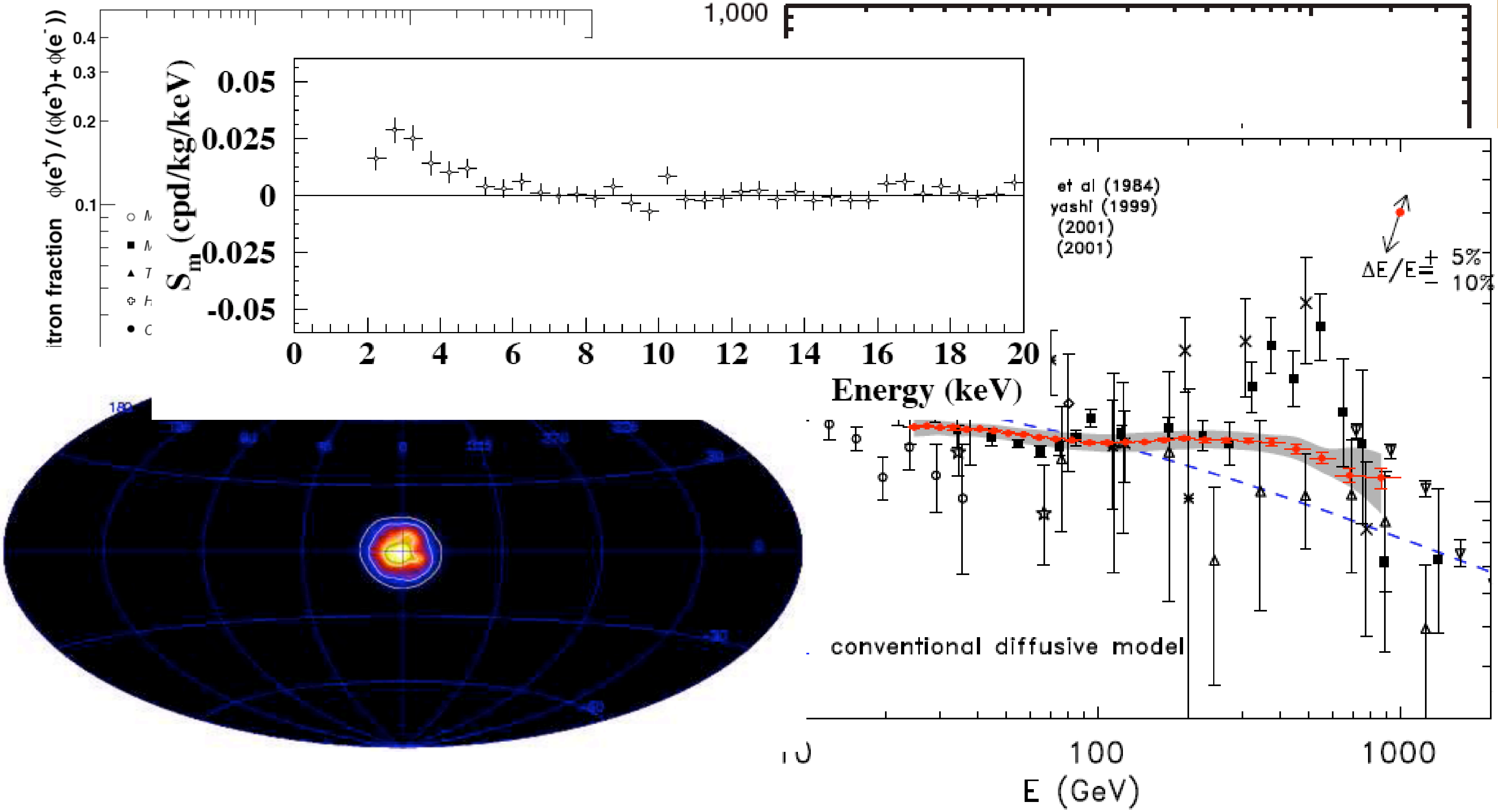

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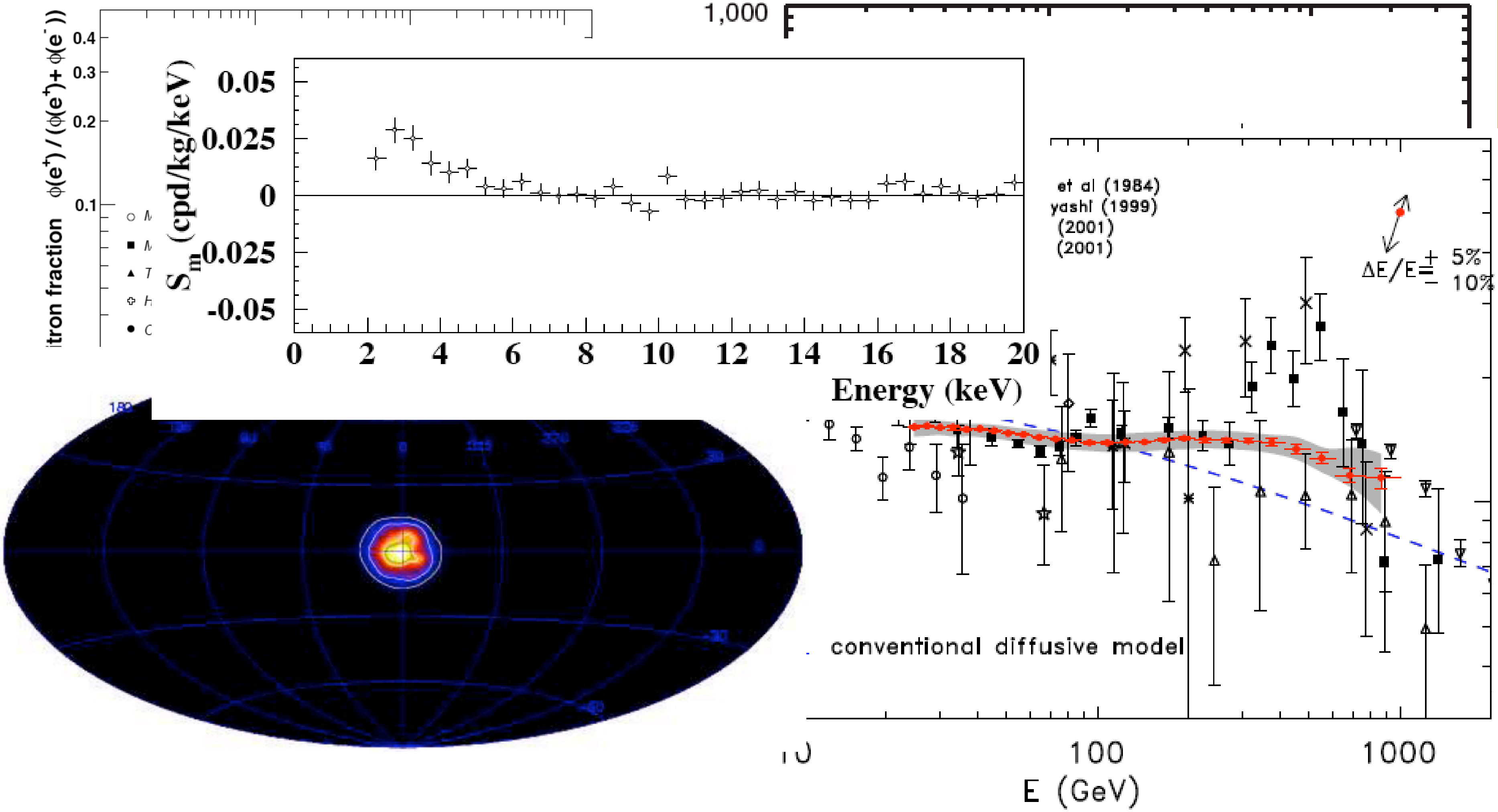

A Theory of DM - Arkani-Hamed, Finkbeiner, Slatyer, and Weiner (0810.0713)

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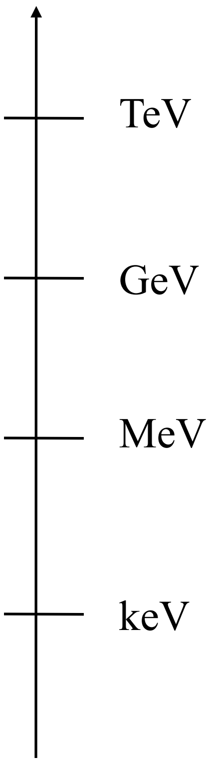

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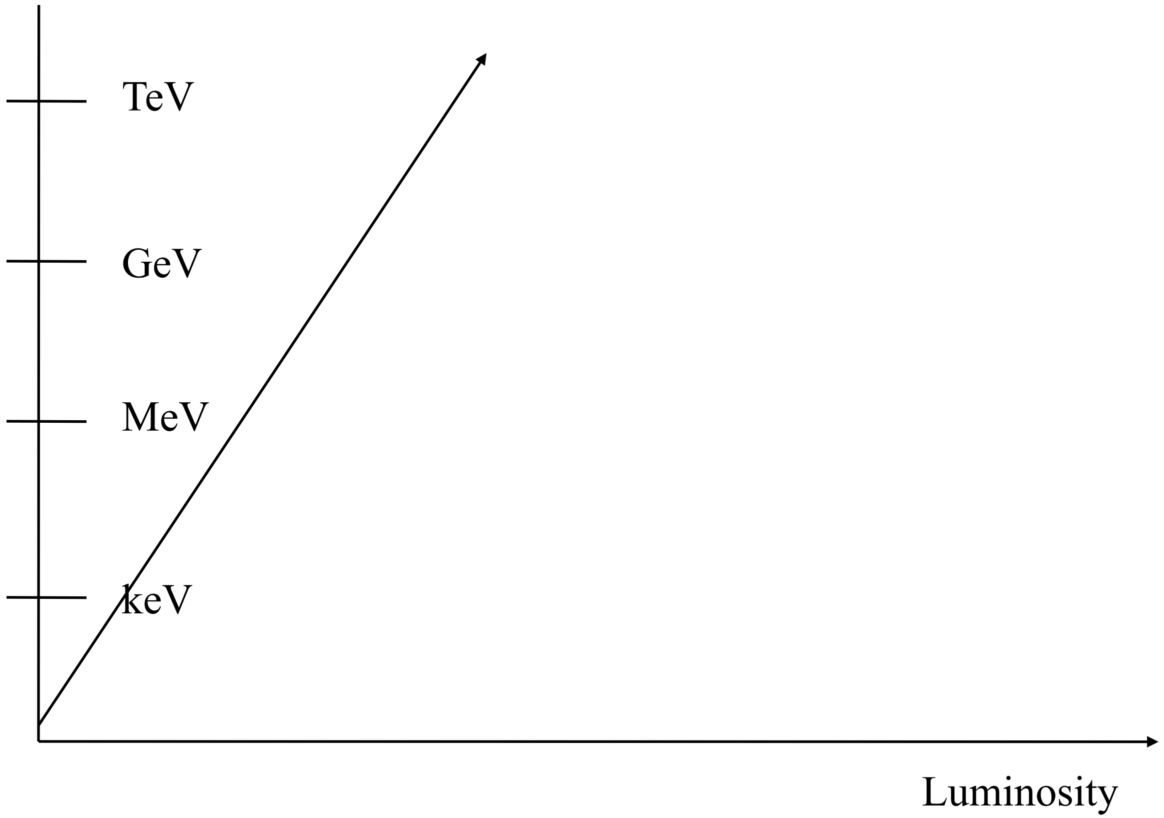

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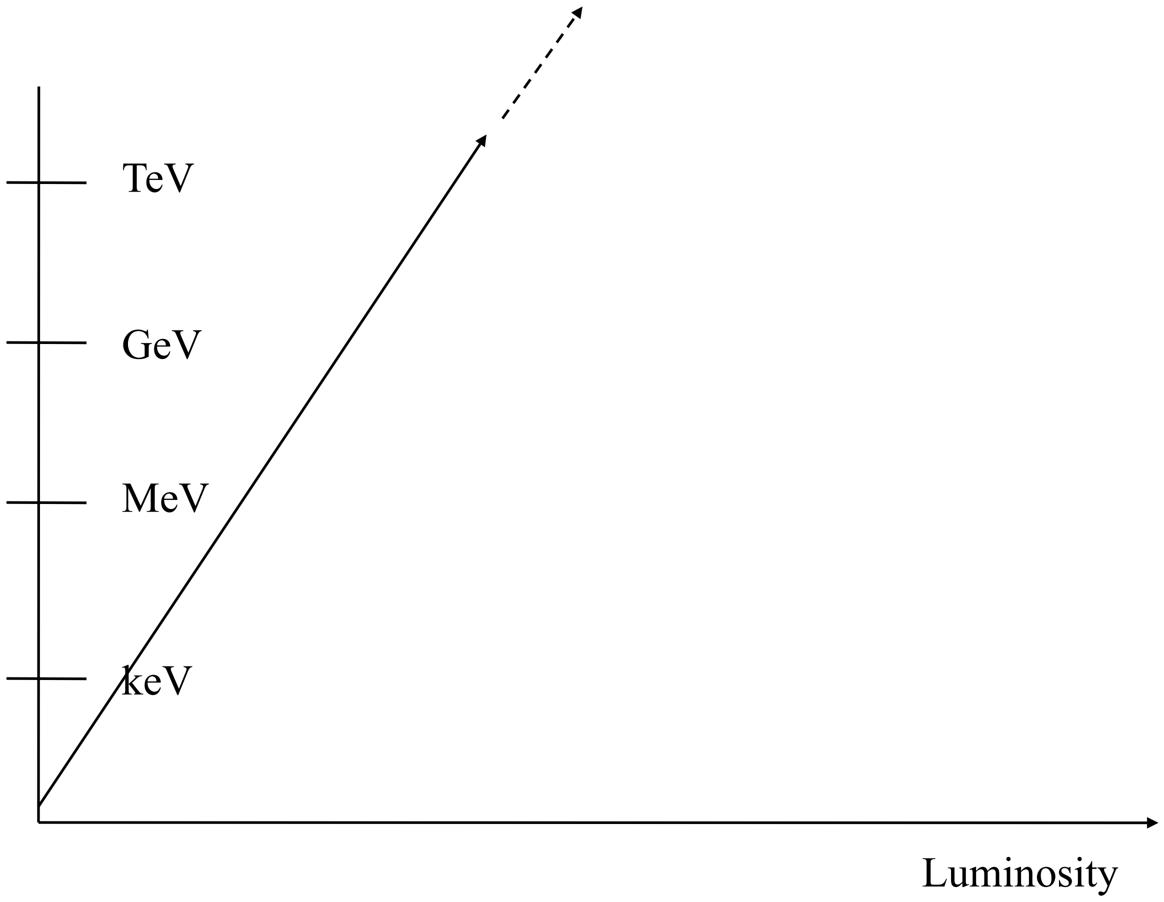

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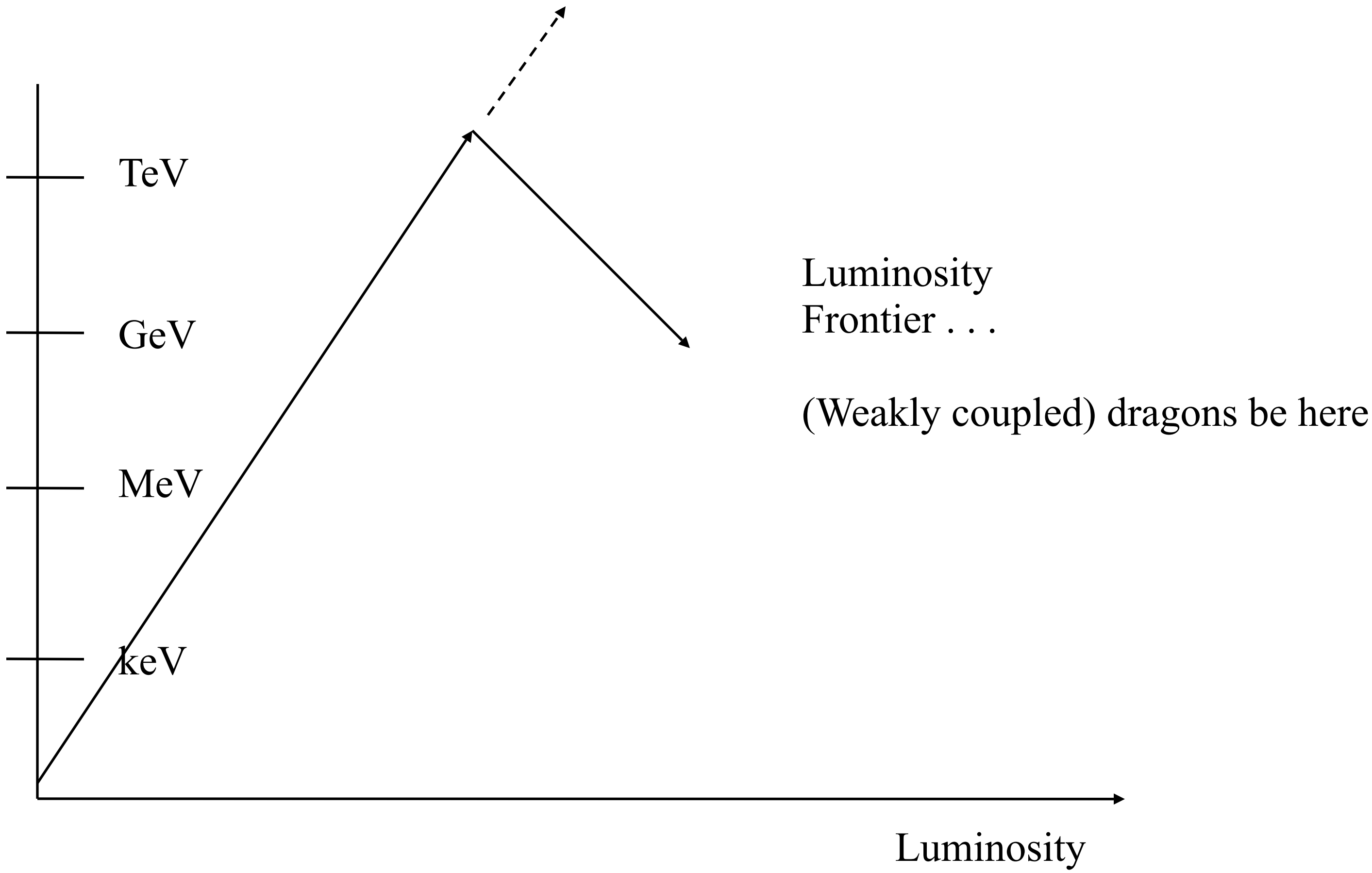

A Tale of Two Sectors

$$\mathcal{L}_{\rm SM} = \ldots$$

http://pdg.lbl.gov

Secluded DM - Pospelov, Ritz, and Voloshin (0711.4866)
A Theory of DM - Arkani-Hamed, Finkbeiner, Slatyer, and Weiner (0810.0713)

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$$M \sim \text{TeV}$$

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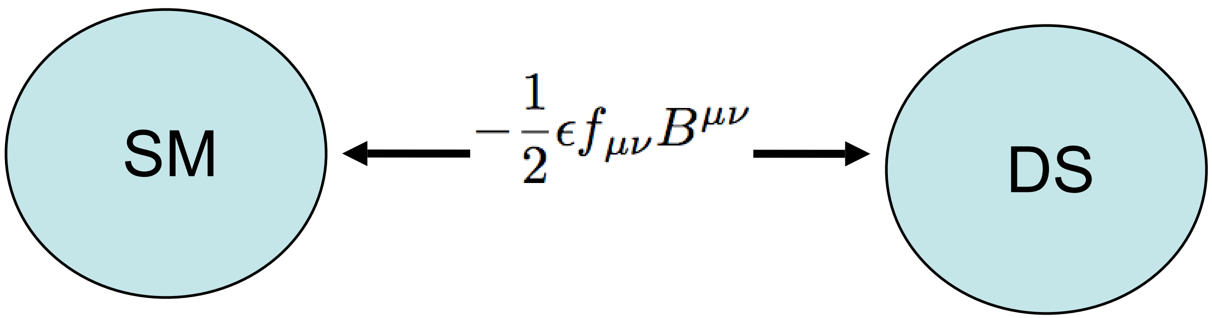

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Dark Spectrum

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$M\bar{\chi}\chi$

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GeV

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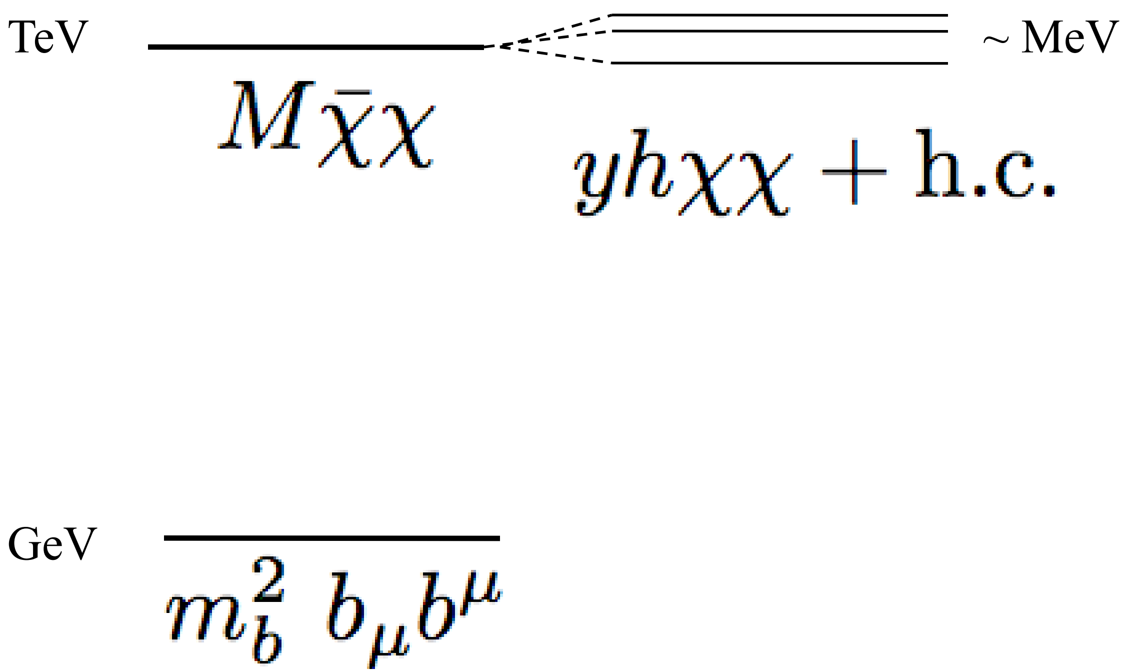

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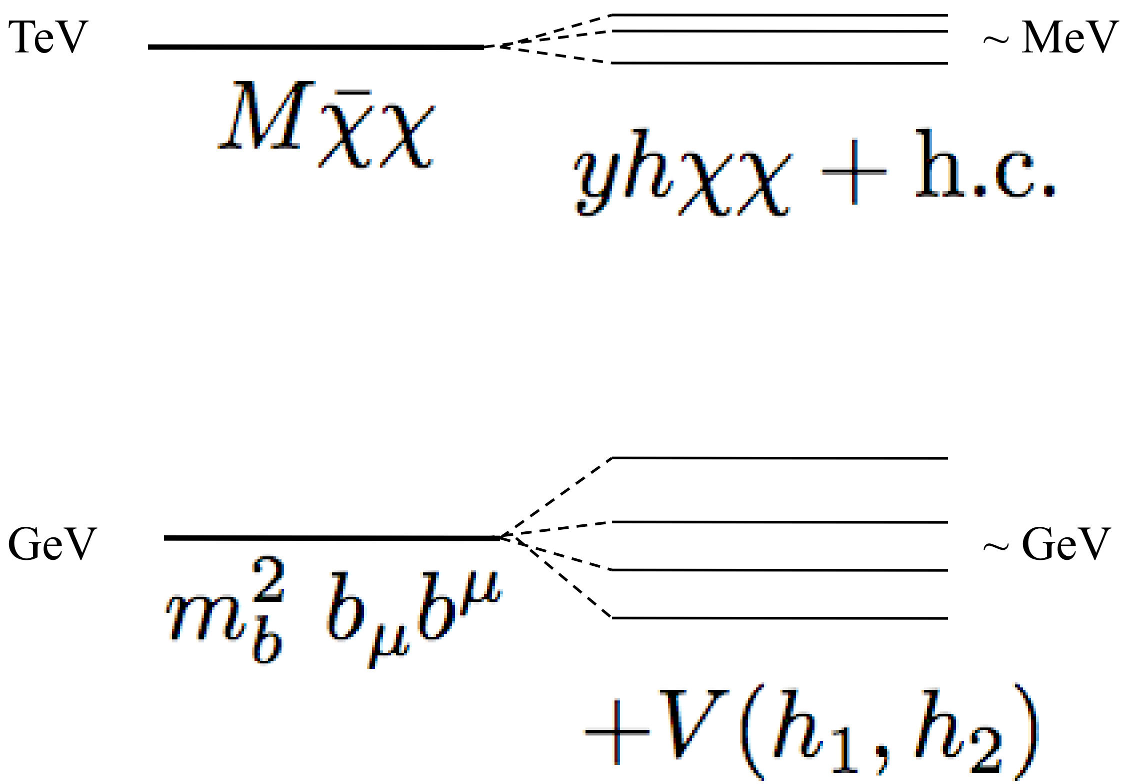

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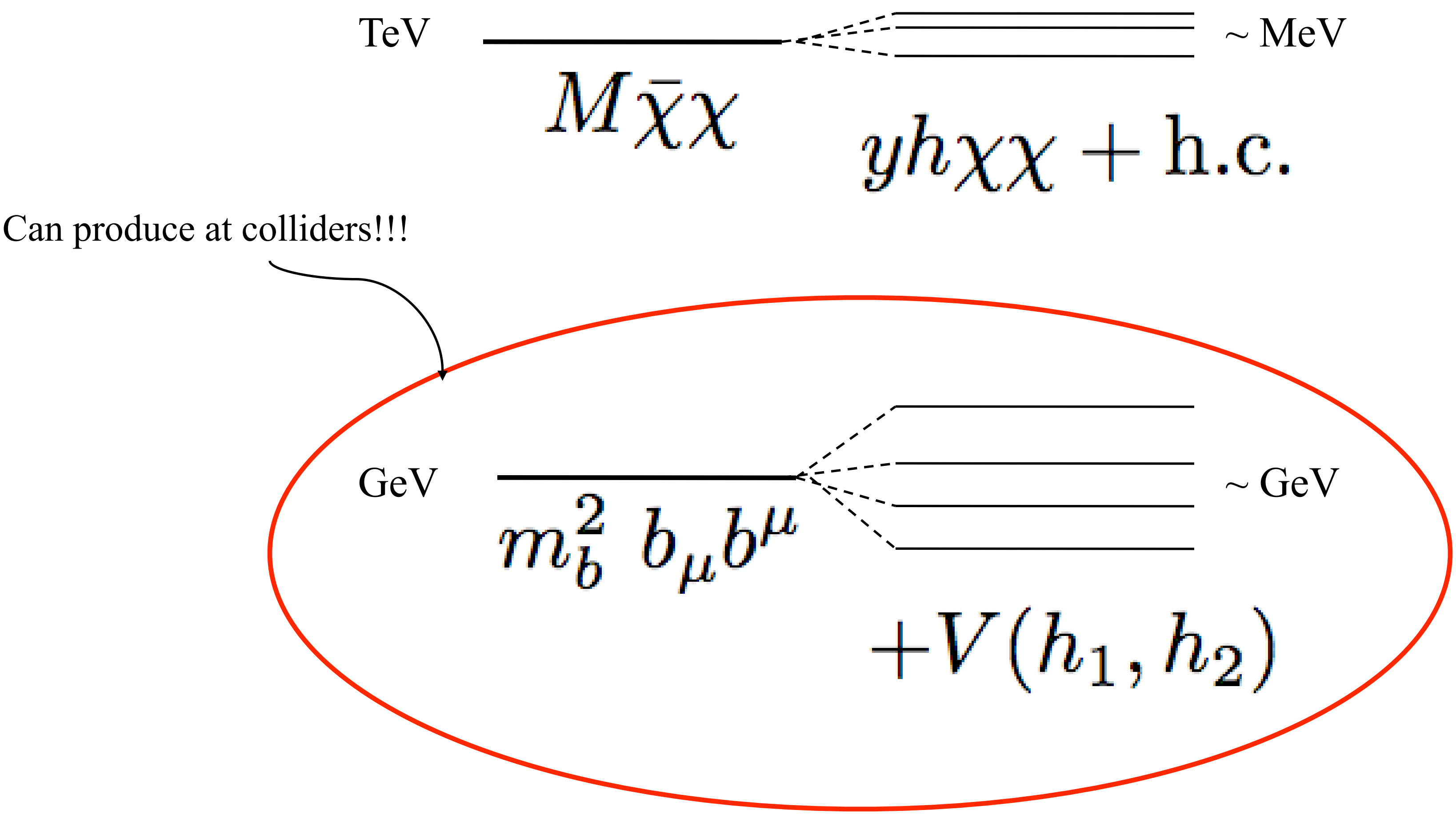
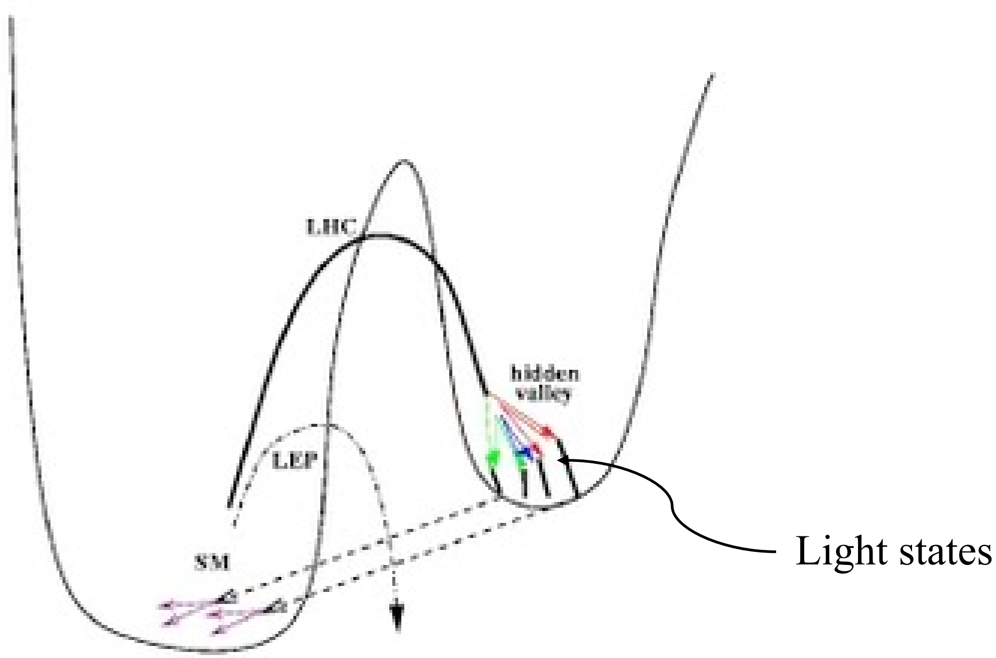


Hidden Valleys

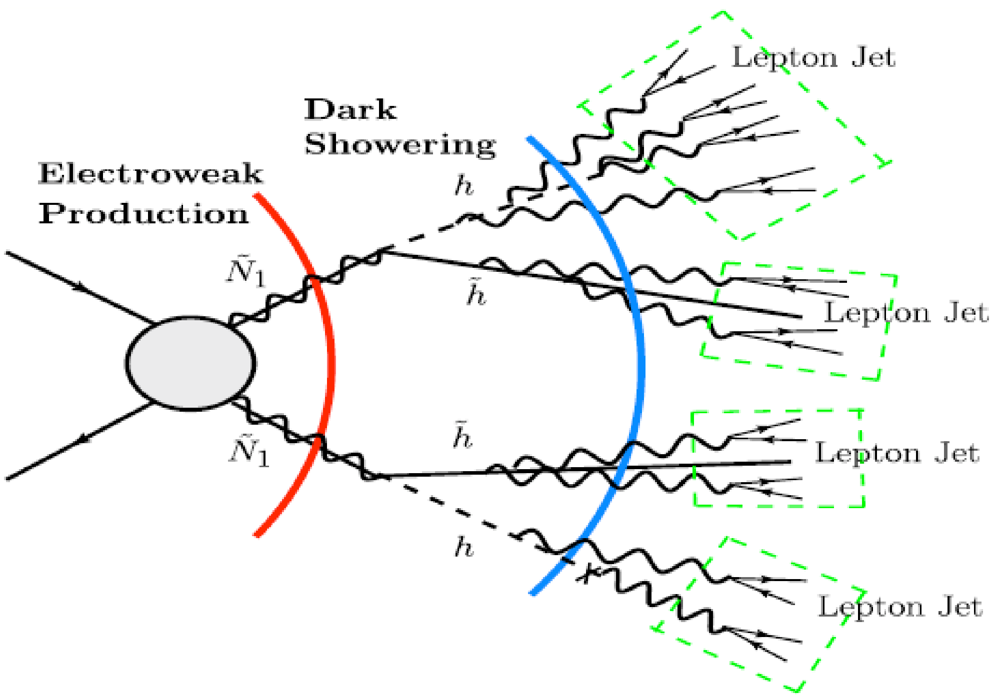
Strassler and Zurek's proposal of hidden valleys share some of the phenomenology and lepton jet searches can in principle be sensitive to these type of models as well,



* Taken (without permission) from Strassler's talk.

Part II

Production and Evolution of Dark States



Coupling to the Standard Model

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In general the dark gauge-boson can mix with both the photon and the Z^0,

$$\begin{aligned}\mathcal{L}_{\text{gauge mix}} &= -\frac{1}{2}\epsilon_1 b_{\mu\nu}A^{\mu\nu} - \frac{1}{2}\epsilon_2 b_{\mu\nu}Z^{\mu\nu} \\ &= -\frac{1}{2}\epsilon_1' b_{\mu\nu}B^{\mu\nu} - \frac{1}{2}\epsilon_2' b_{\mu\nu}W_3^{\mu\nu}\end{aligned}$$

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If supersymmetry is only softly broken in the dark sector, then there is also an important mixing of the electroweak gauginos with the dark gaugino:

$$\mathcal{L}_{\text{gaugino mix}} = -2i\epsilon_1' \tilde{b}^\dagger \bar{\sigma}^\mu \partial_\mu \tilde{B} - 2i\epsilon_2' \tilde{b}^\dagger \bar{\sigma}^\mu \partial_\mu \tilde{W}_3 + \text{h.c.}$$

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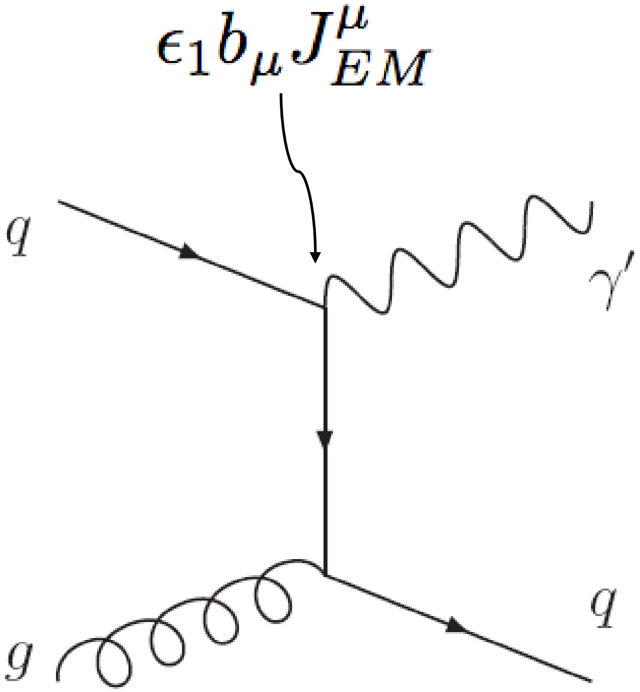
All in all we have the following couplings (after diagonalization and etc.), which act as a portal to the dark sector

$$\mathcal{L}_{\text{portal}} = \epsilon_1 b_\mu J^\mu_{\text{EM}} + \epsilon_2 Z_\mu J_b + \epsilon_1'\tilde{B}\tilde{J}_{\tilde{b}} + \epsilon_2'\tilde{W}_3\tilde{J}_{\tilde{b}}$$

Prompt (Dark) Photon Production

The coupling to the electromagnetic current allows for the production of the dark photon in a similar manner to a prompt photon (Baumgart et al. 0901.0283) :



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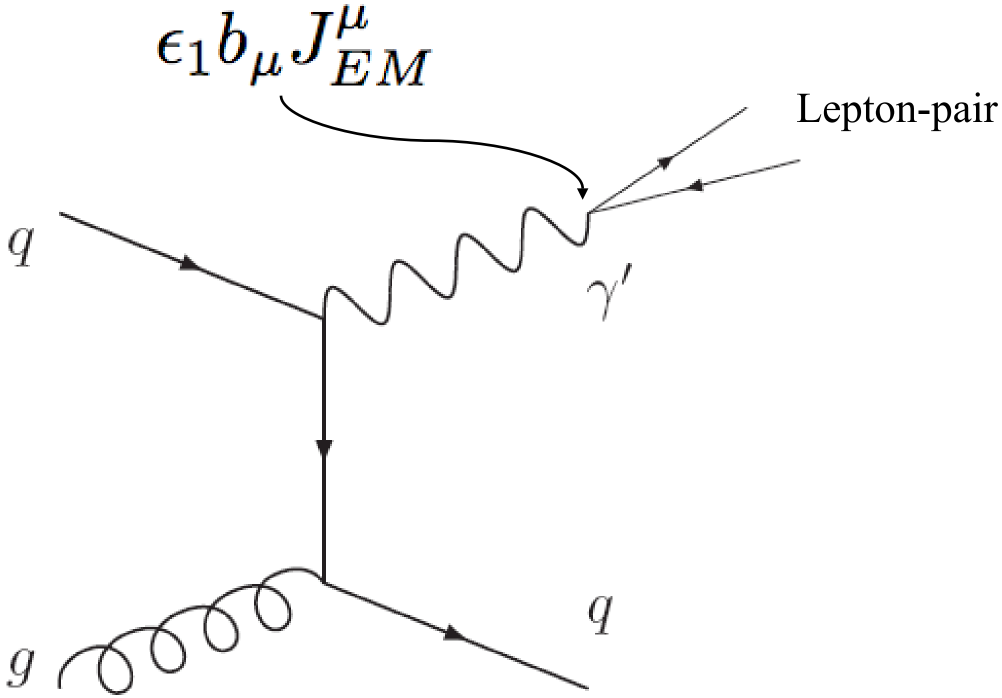

Too much background!!!

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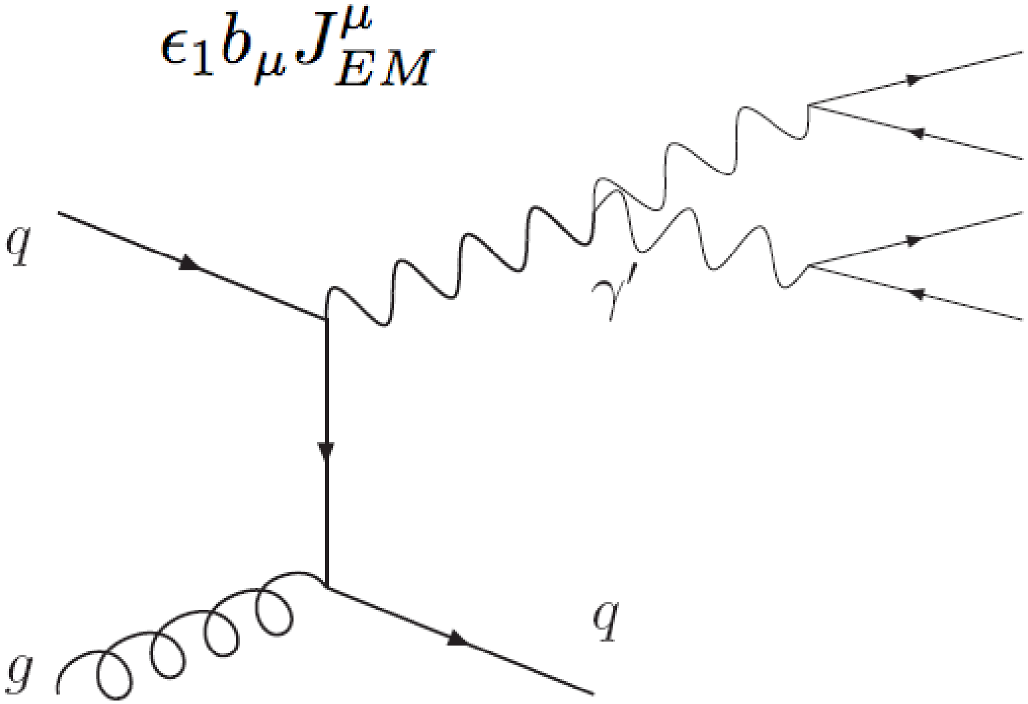

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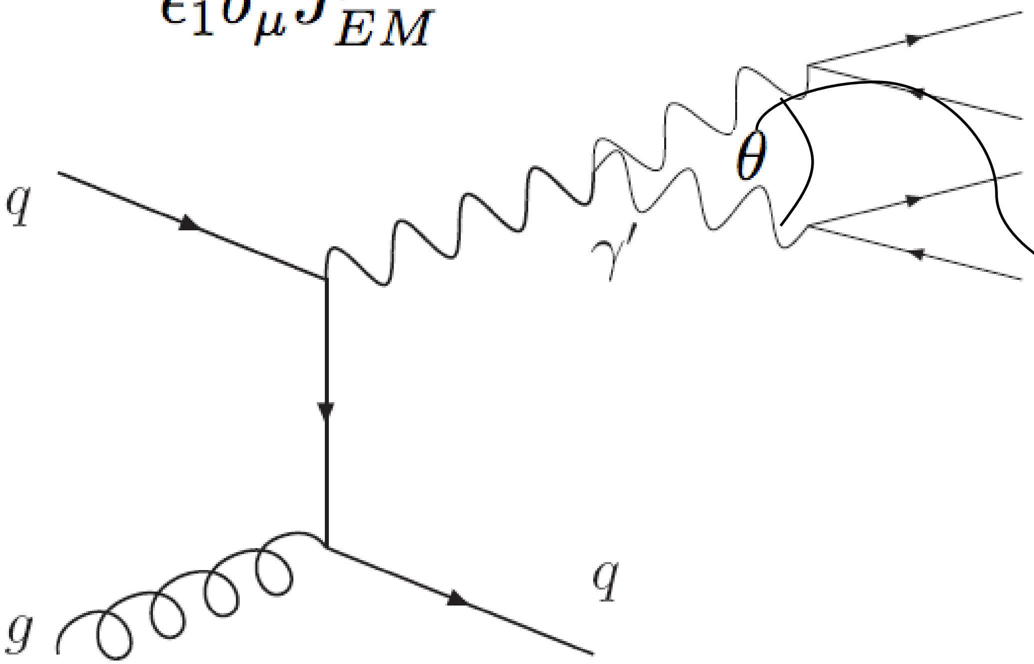

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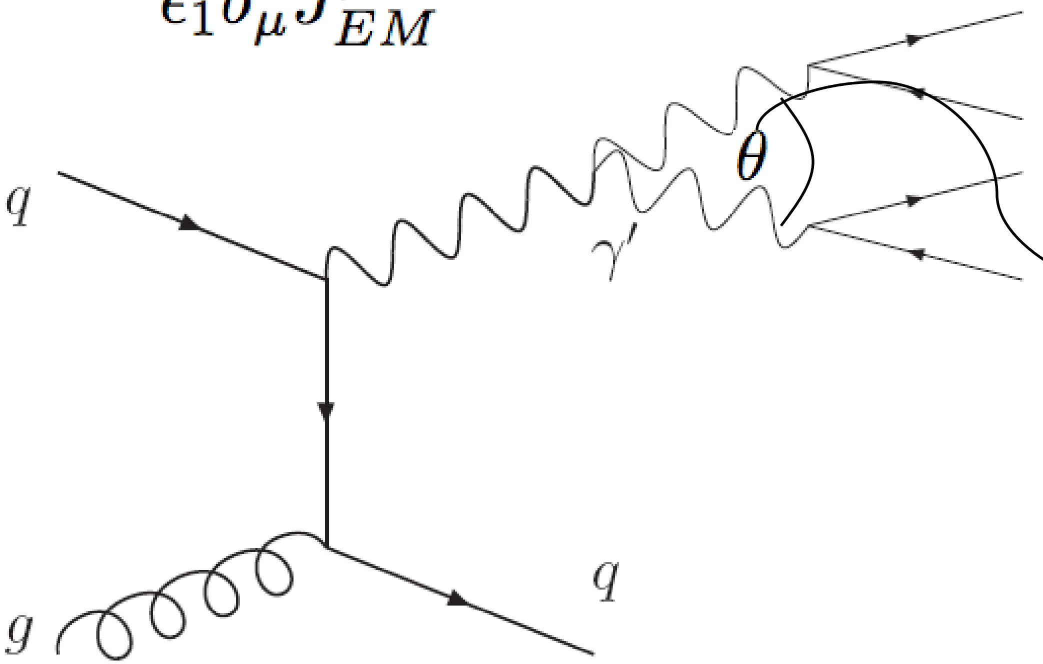

Lepton Jets - A collimated collection of energetic leptons with a small opening angle.

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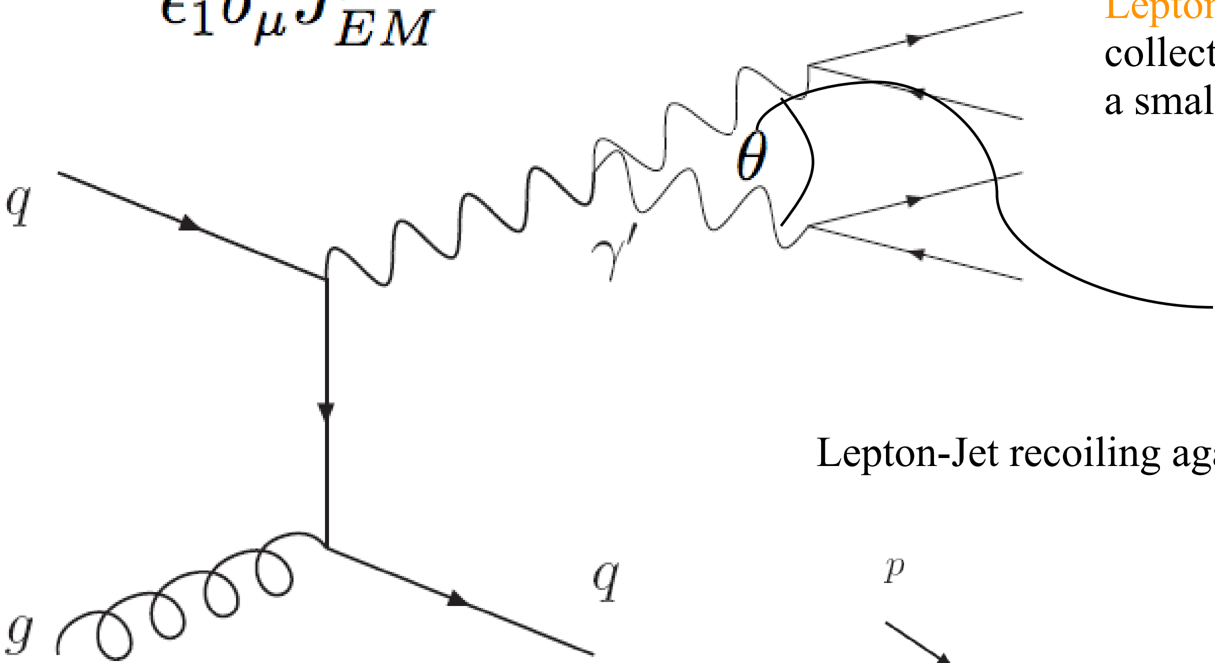

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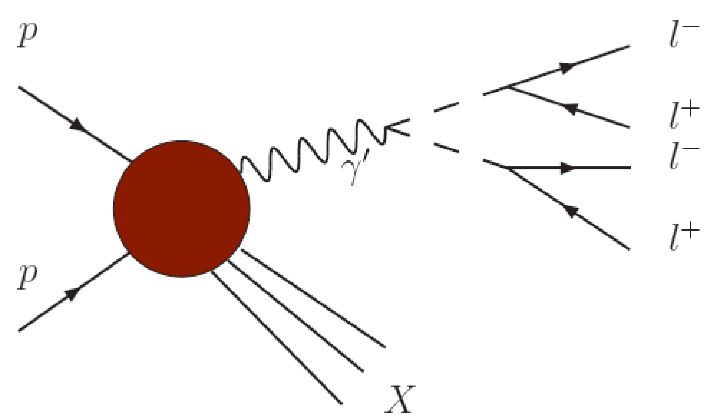
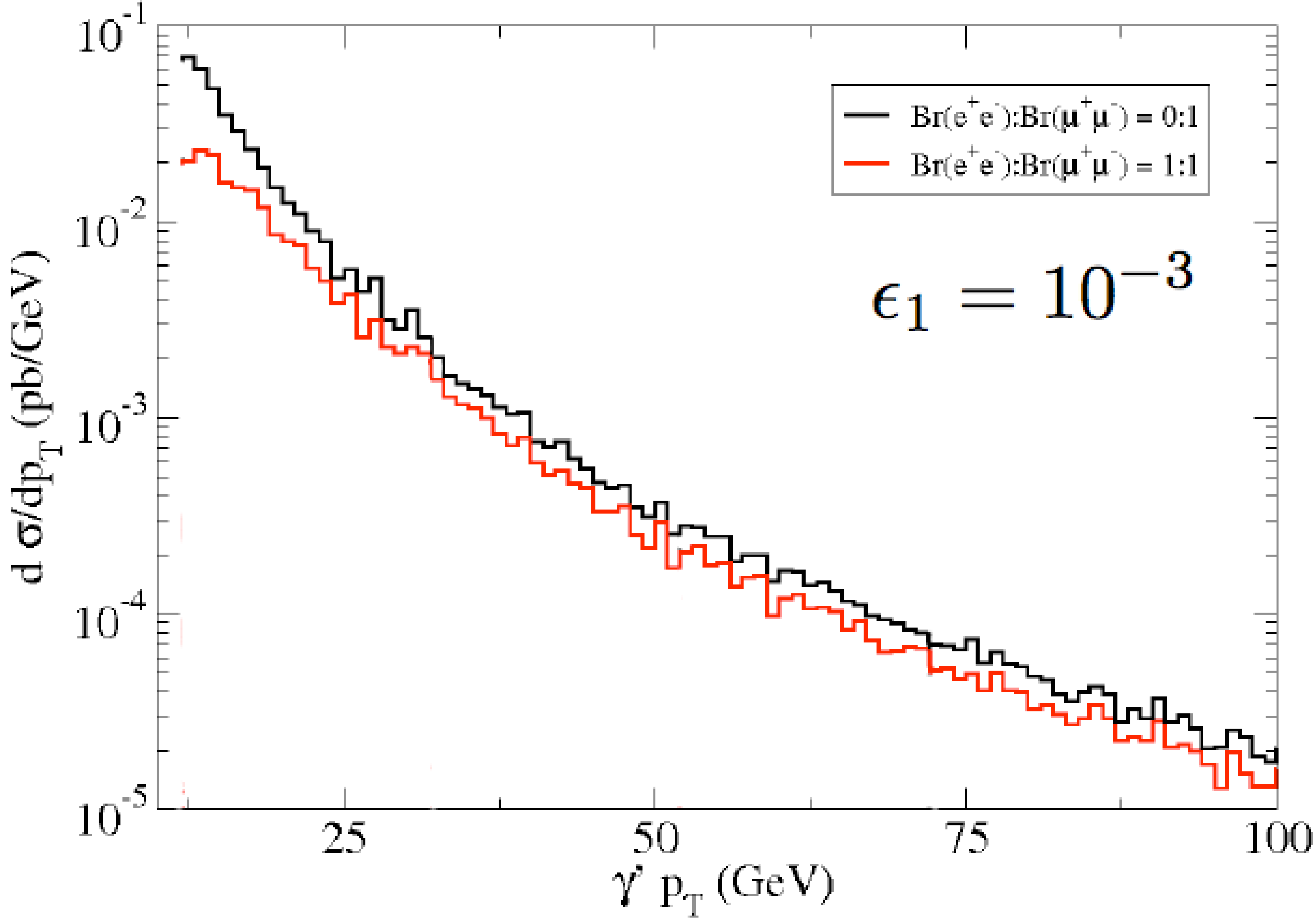
Lepton-Jet recoiling against a QCD jet:



Cross-Sections at the LHC



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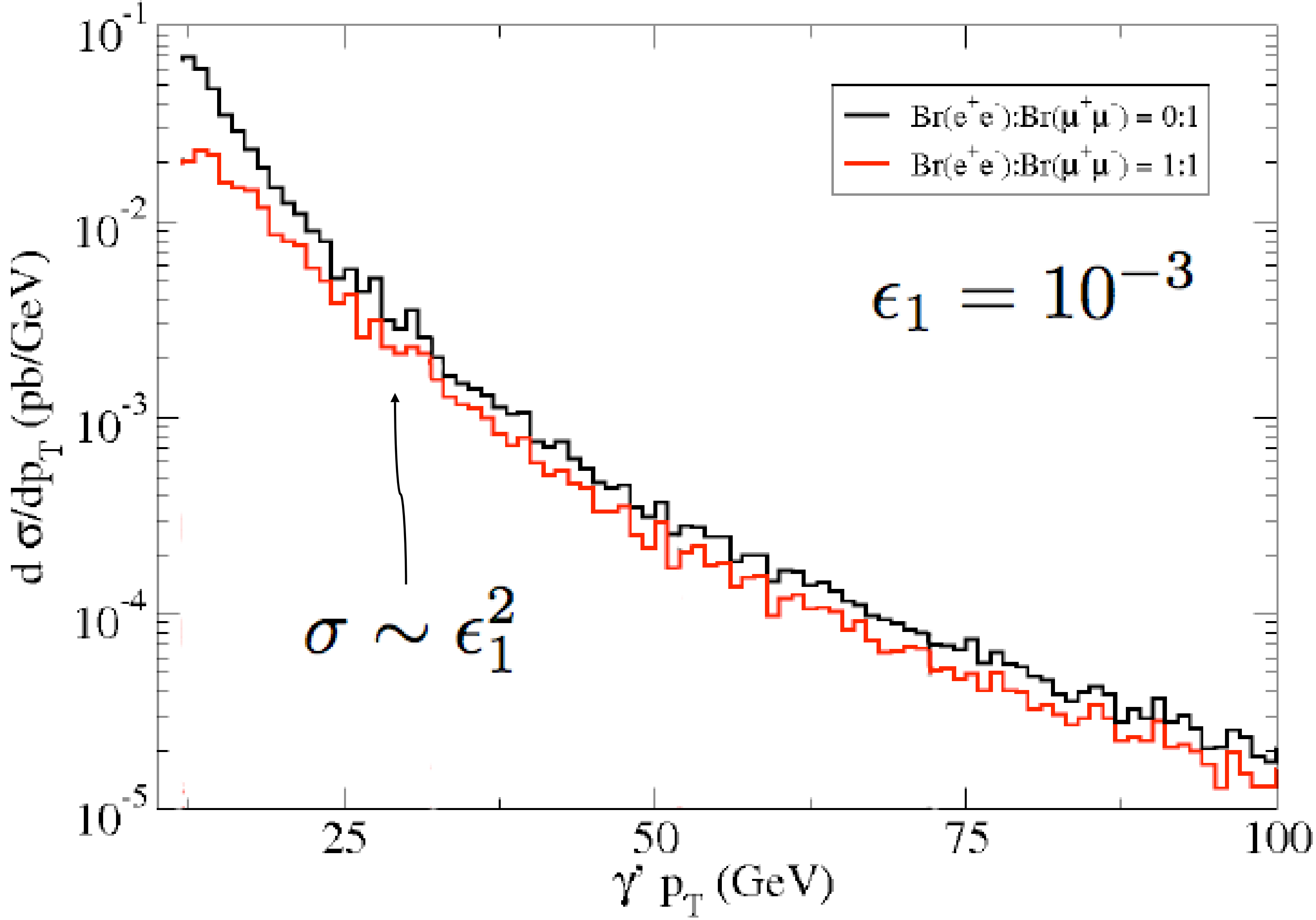

Rare Z^0 Decay

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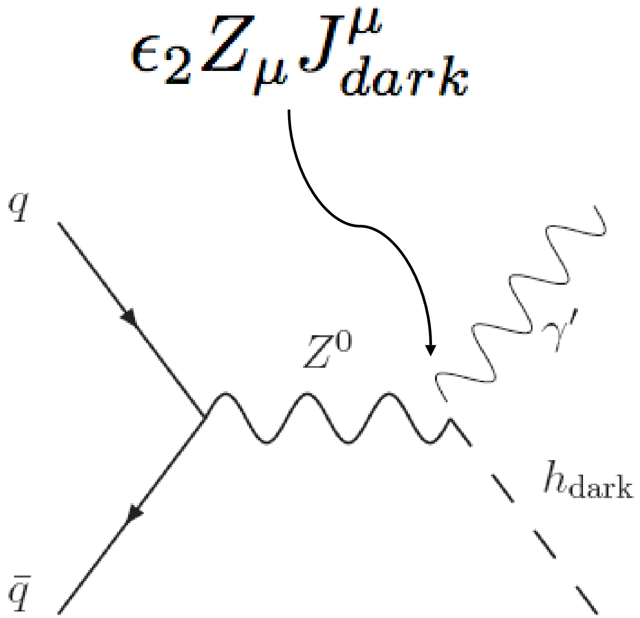

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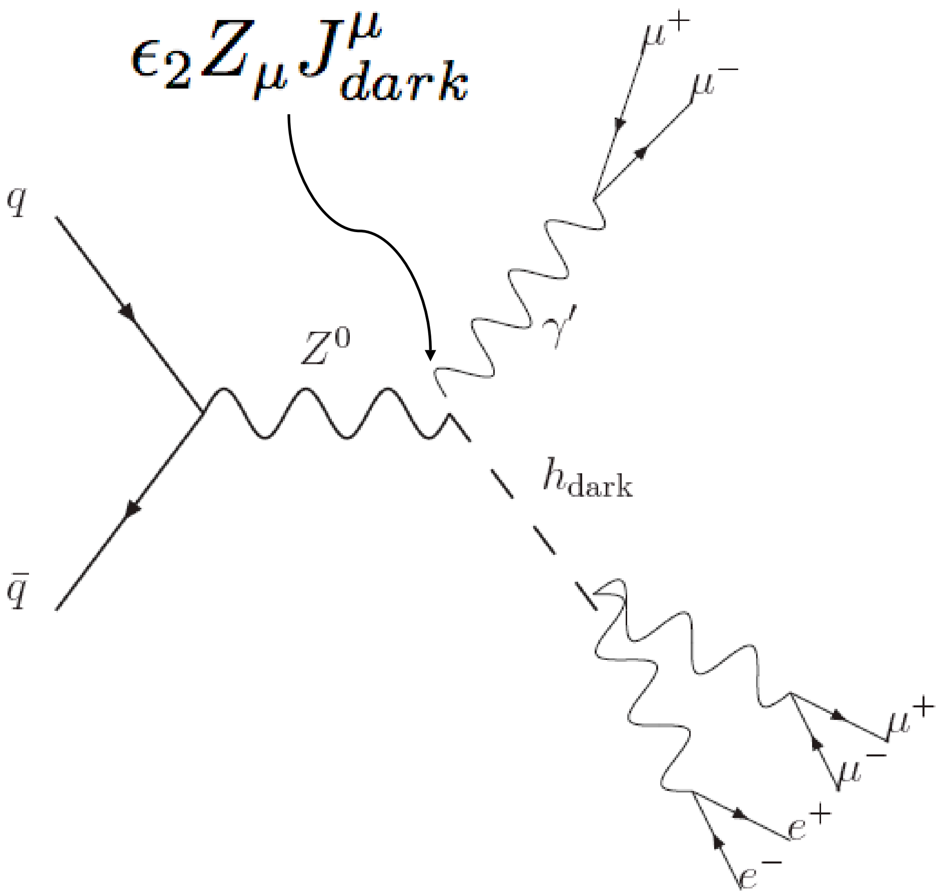

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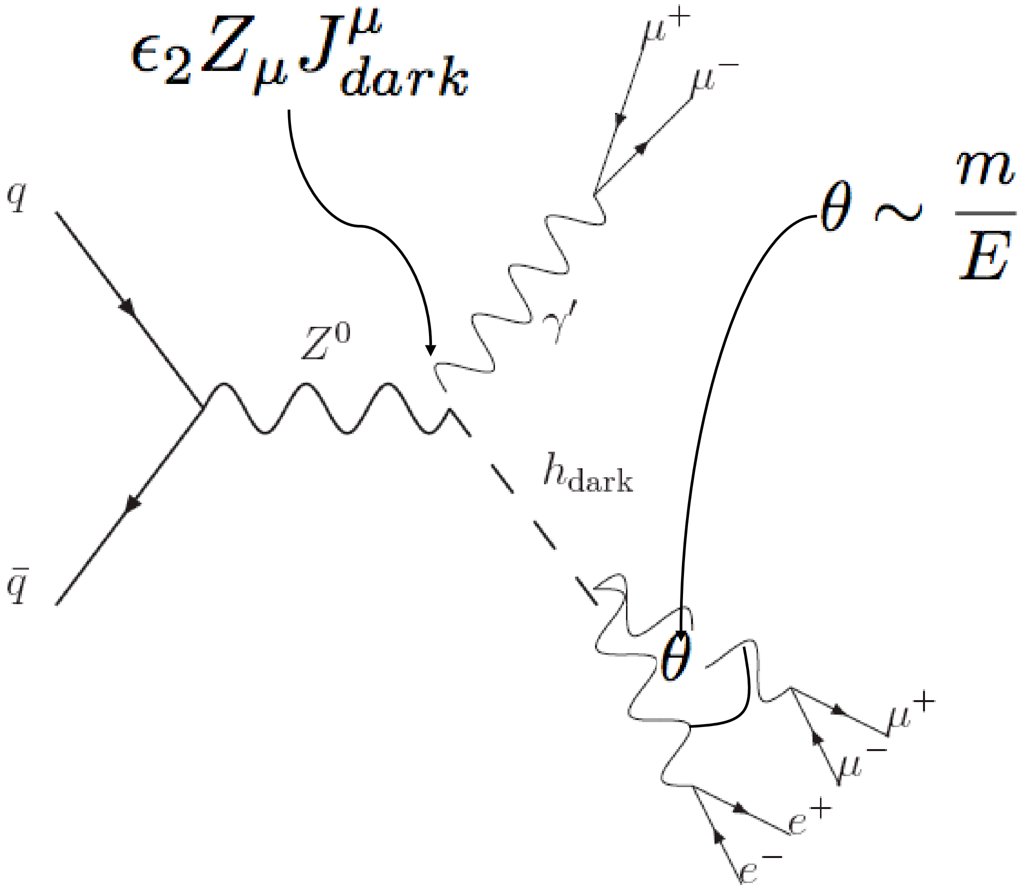
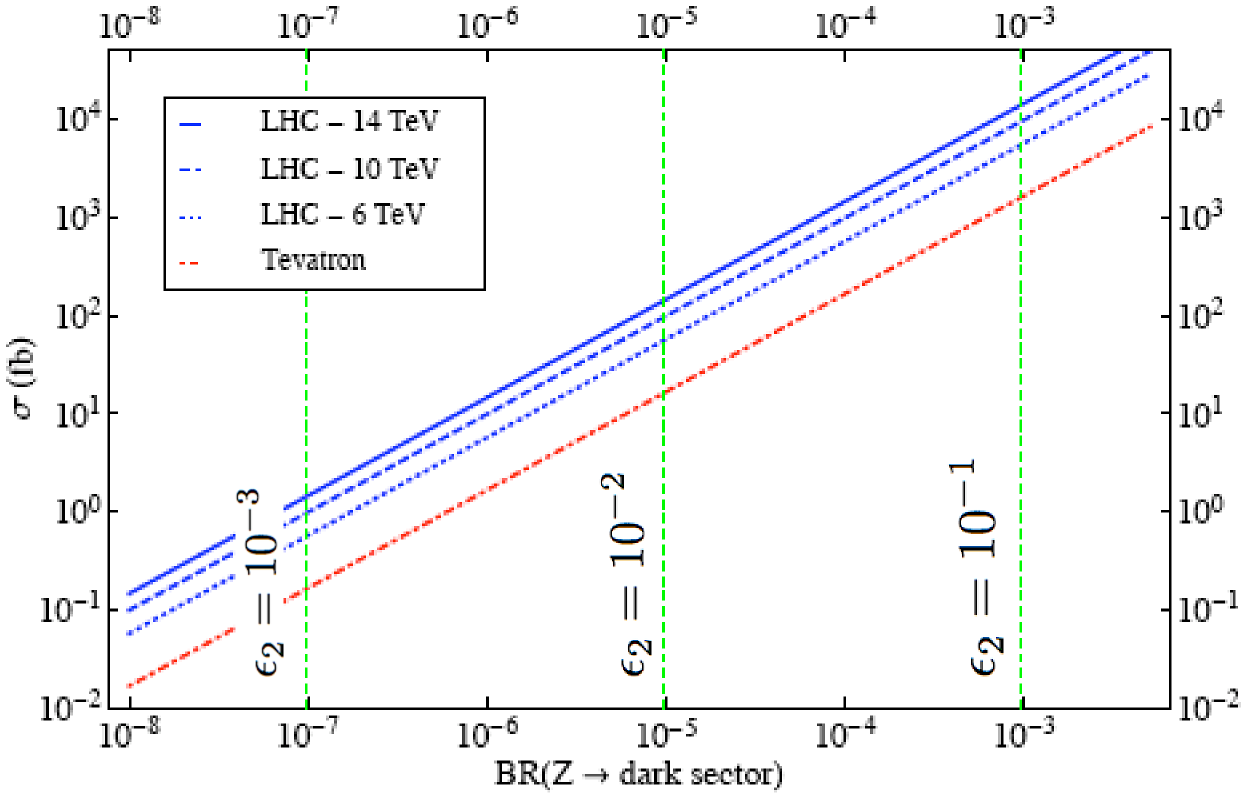


Rare Z^0 Decays - Reach

At LEP : $\mathrm{BR}\left(Z \to f\bar{f}\right) = \frac{\epsilon_2^2 g_{\mathrm{dark}}^2}{12\pi} \frac{M_{Z^0}}{\Gamma_{Z^0}}$ ➡ $\mathcal{O}(100)$ events for $\epsilon_2 = 10^{-2}$

At Tevatron and LHC :



Neutralino Decay

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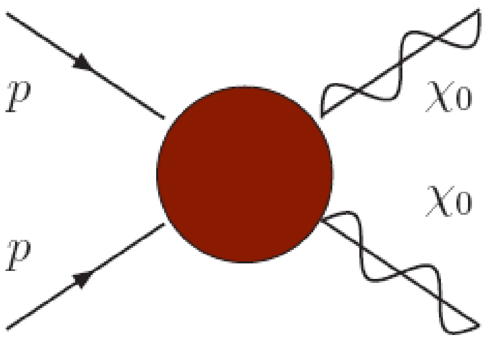

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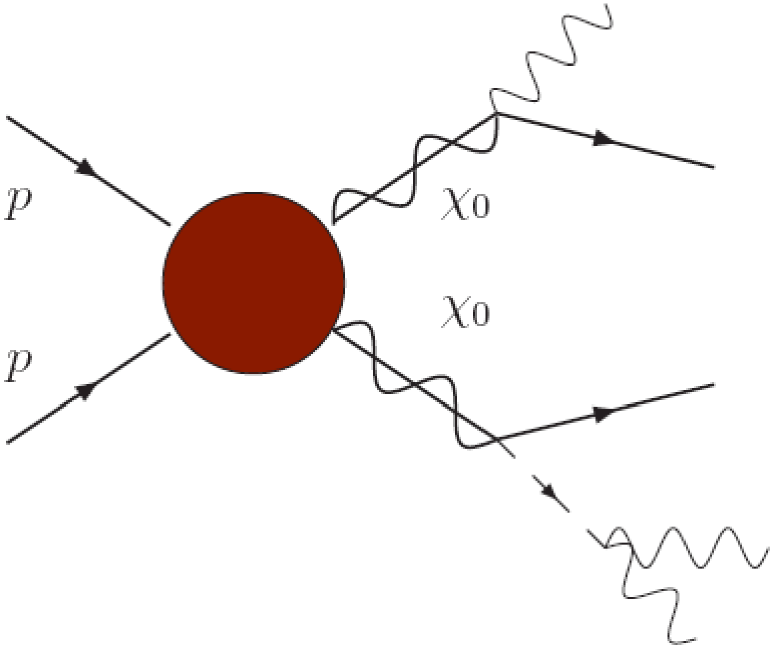

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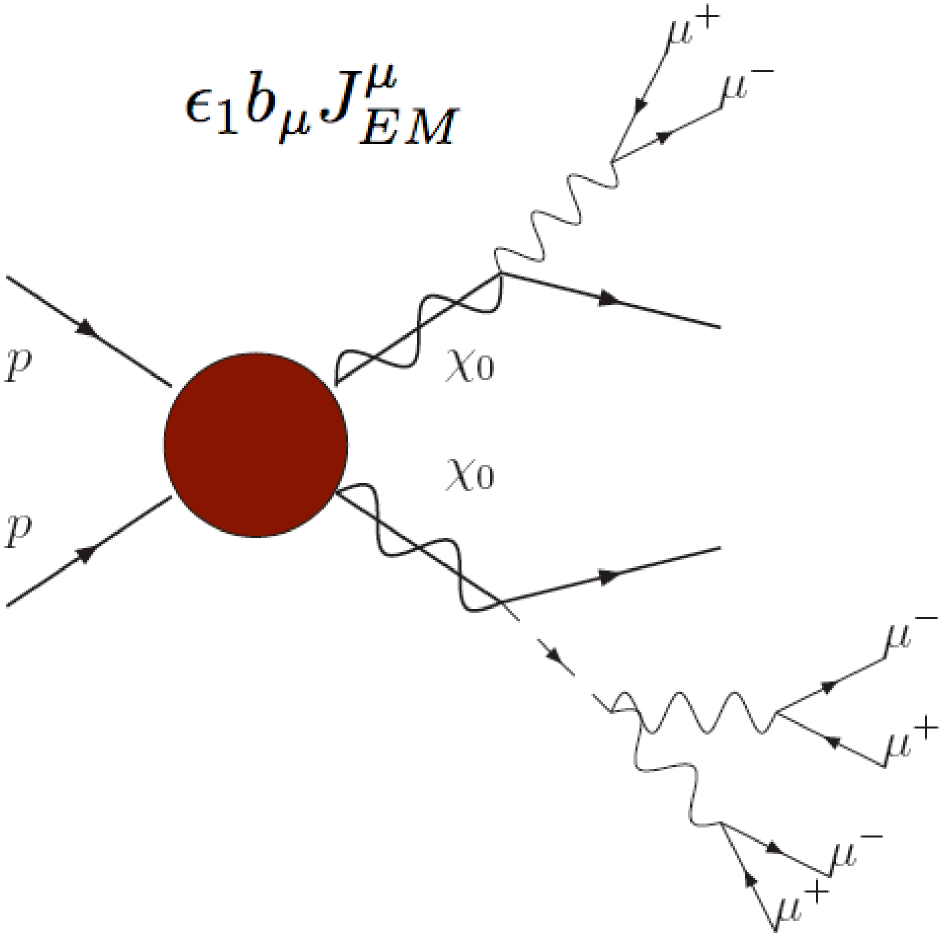

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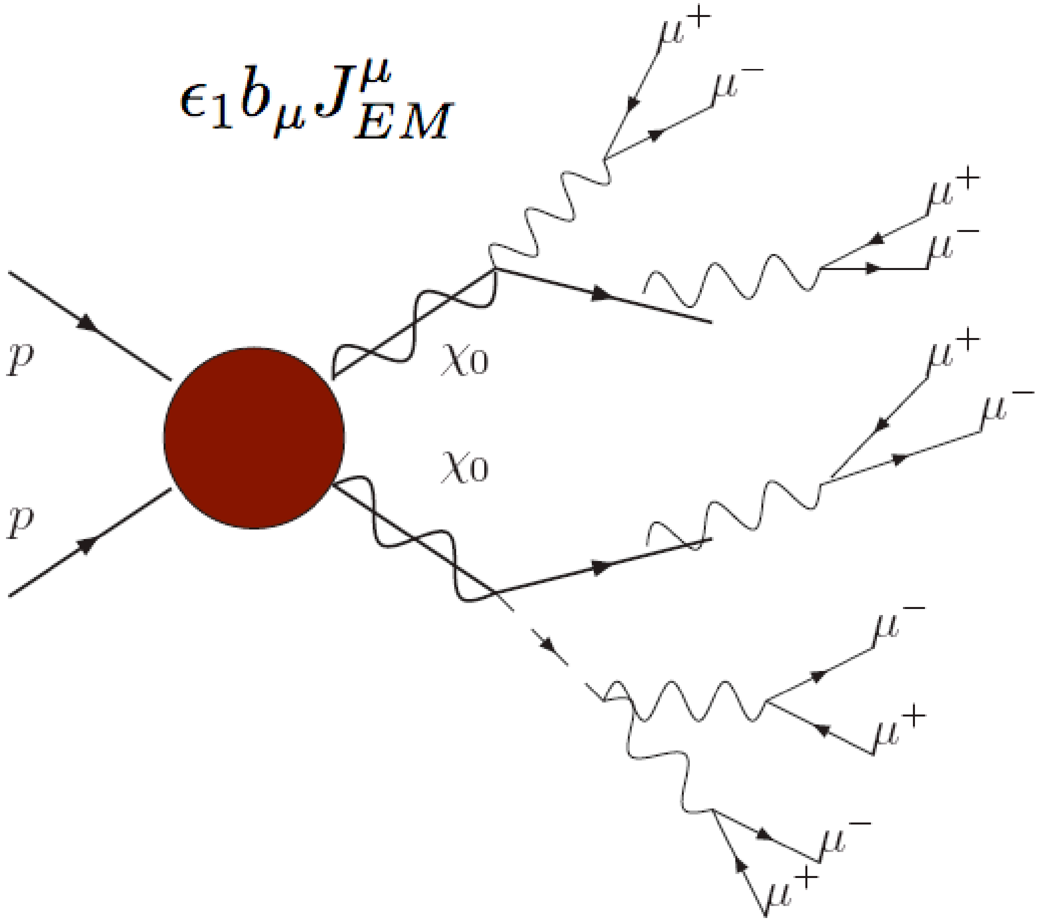

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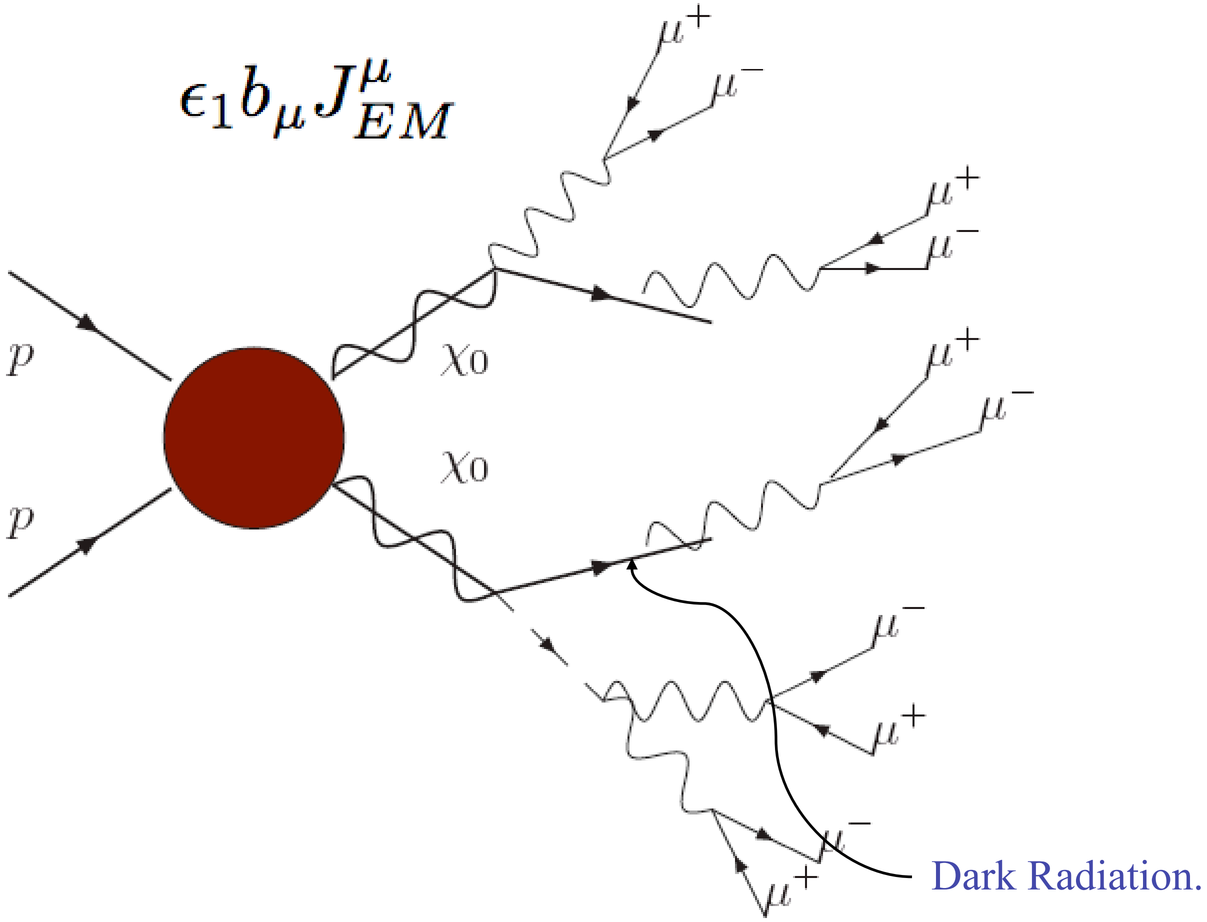

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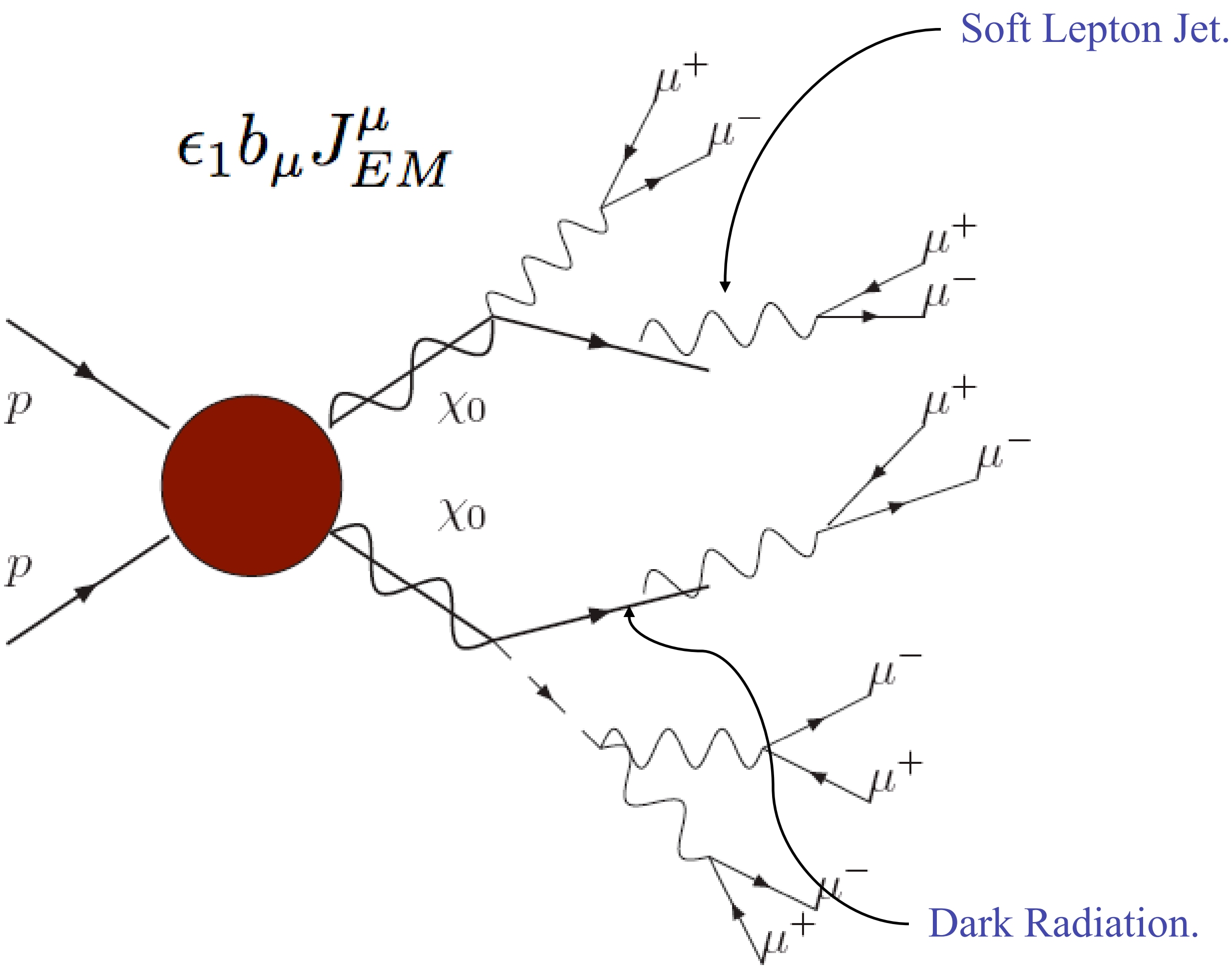

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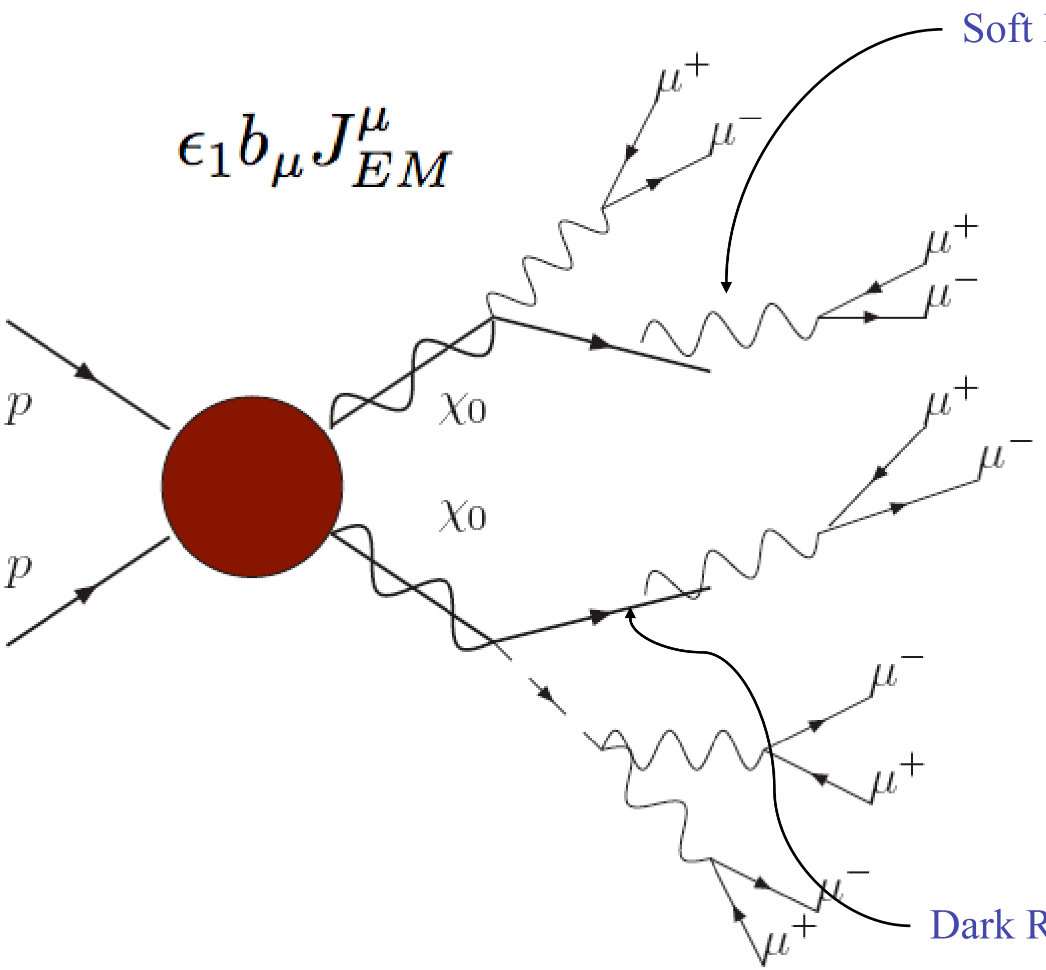
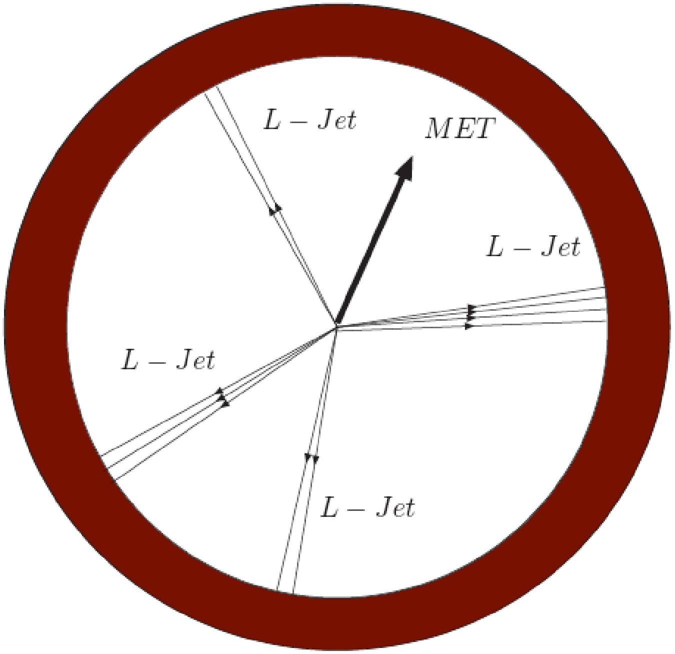
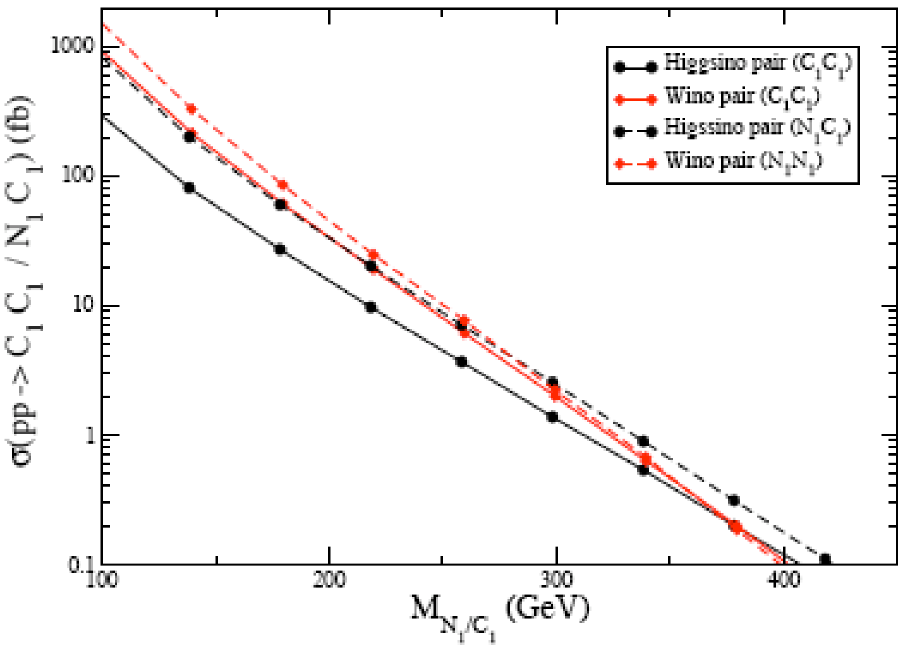
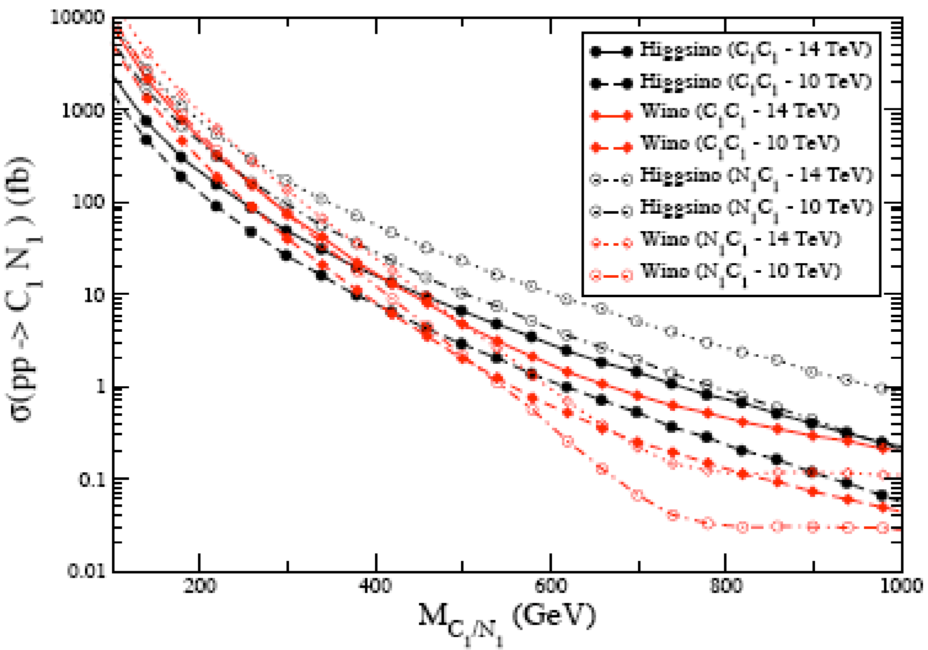




LHC/Tevatron Reach



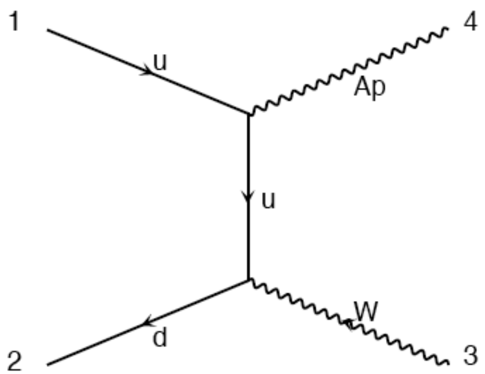


* This is for a squark mass of 750 GeV.

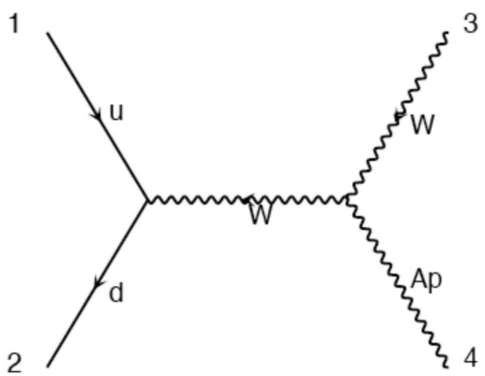
These are large cross-sections.
Some of the parameter space can already be excluded by Tevatron searches…

Dark Photon + W (work in progress. . .)

Similar to the prompt dark photon production we can consider the associate production of a dark photon together with a W boson. You lose on the cross-section, but you gain from the W mass peak.



graph 1



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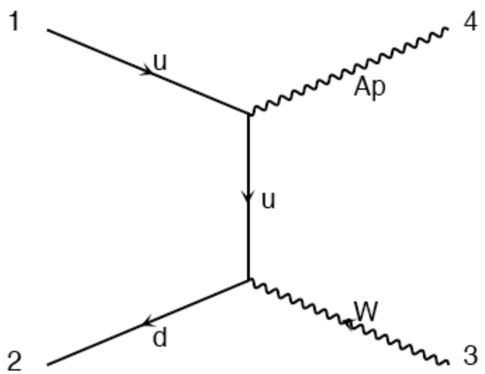

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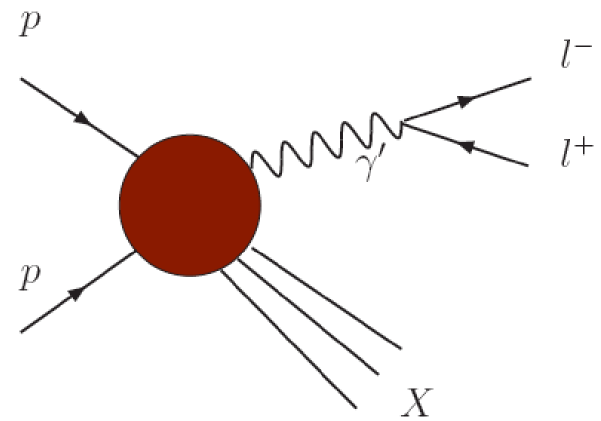

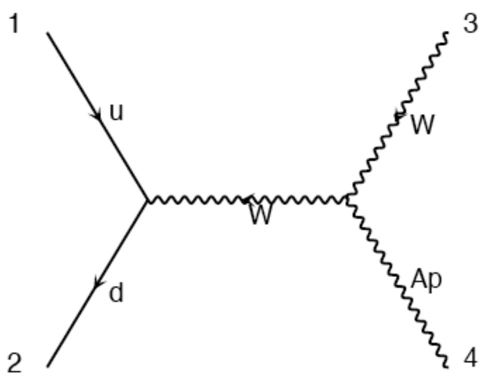

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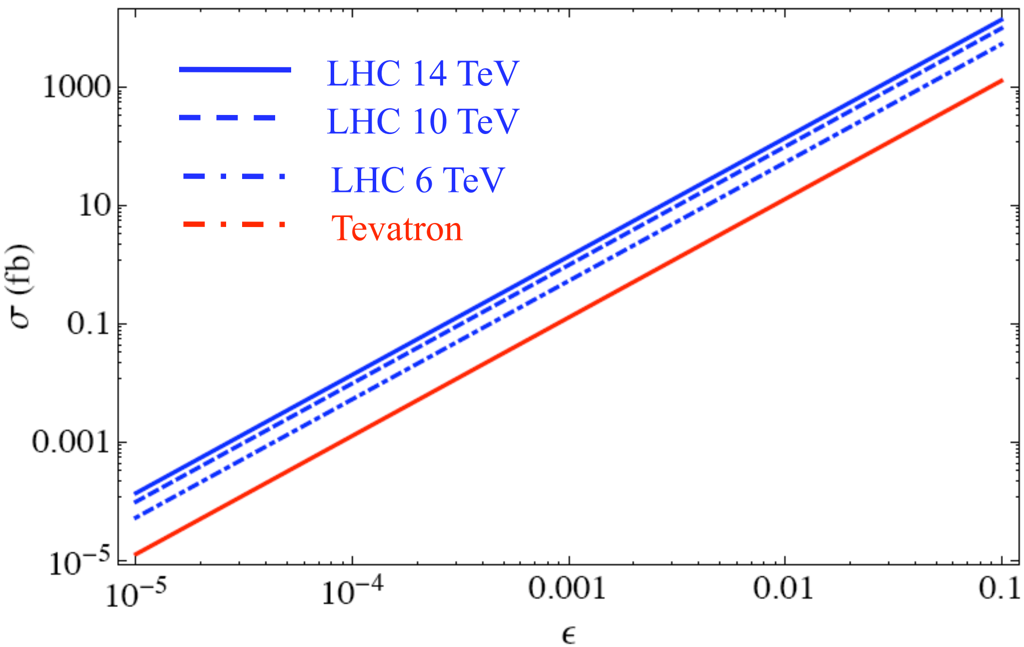


Lepton Jets

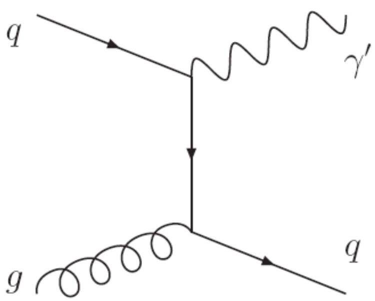
Origin of a Species

Production:

Origin of a Species

Production:

Prompt Dark Photon



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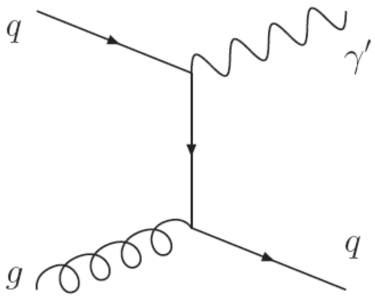
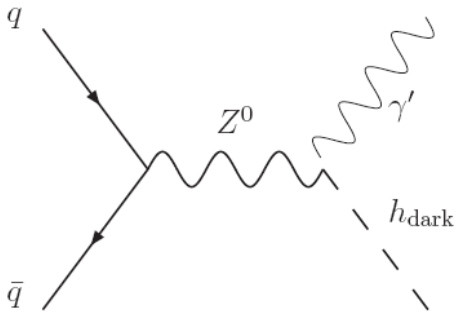


Rare Z^0 decays



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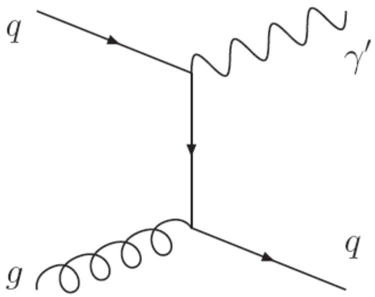

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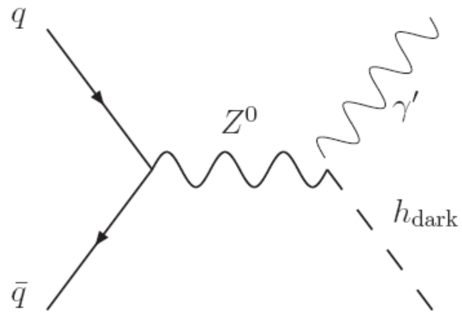
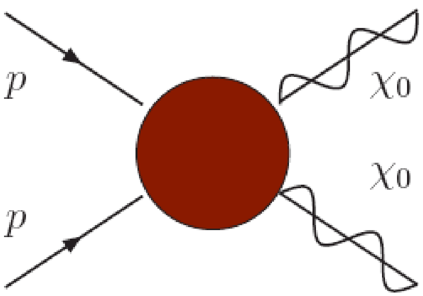


Gaugino Pair Prod



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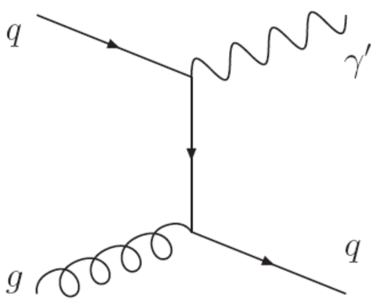

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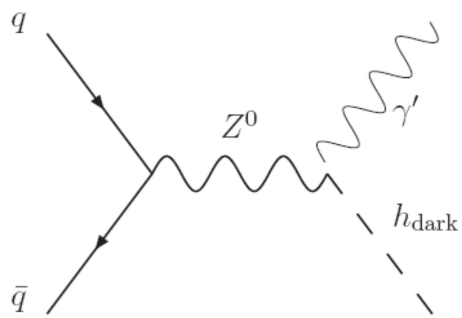

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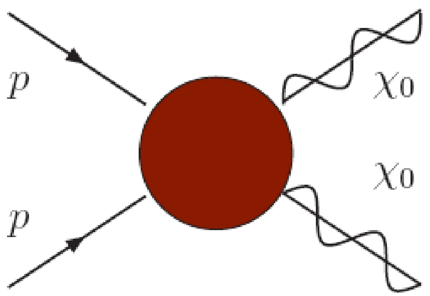

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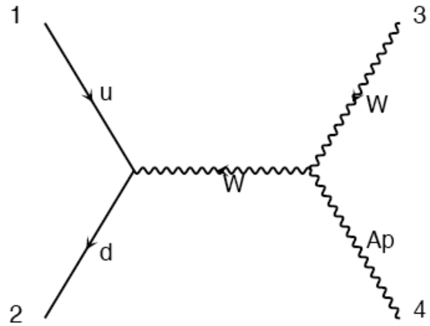

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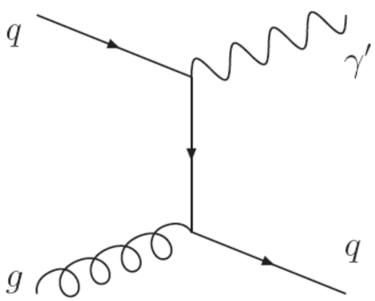

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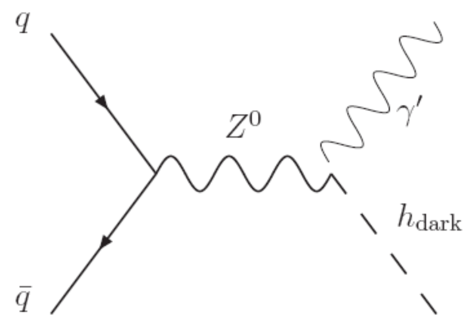

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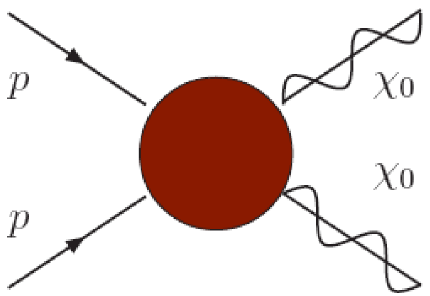

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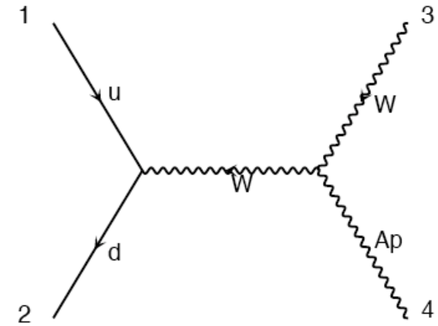

Evolution:

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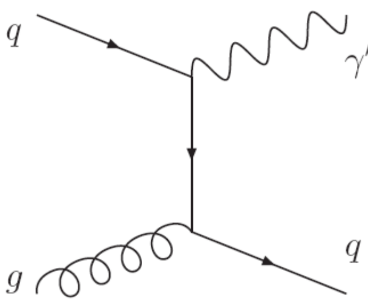

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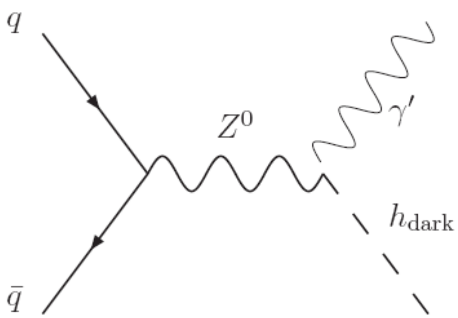

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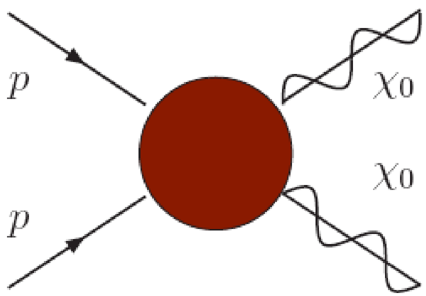

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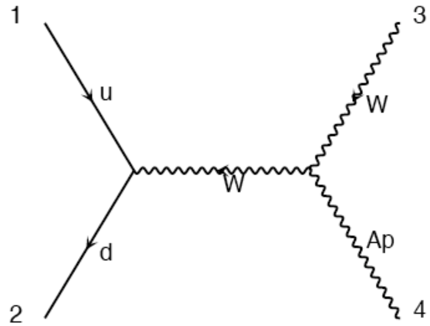
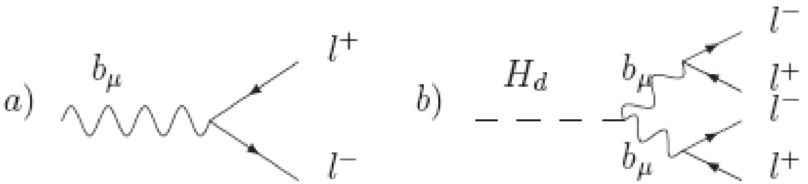


Evolution:

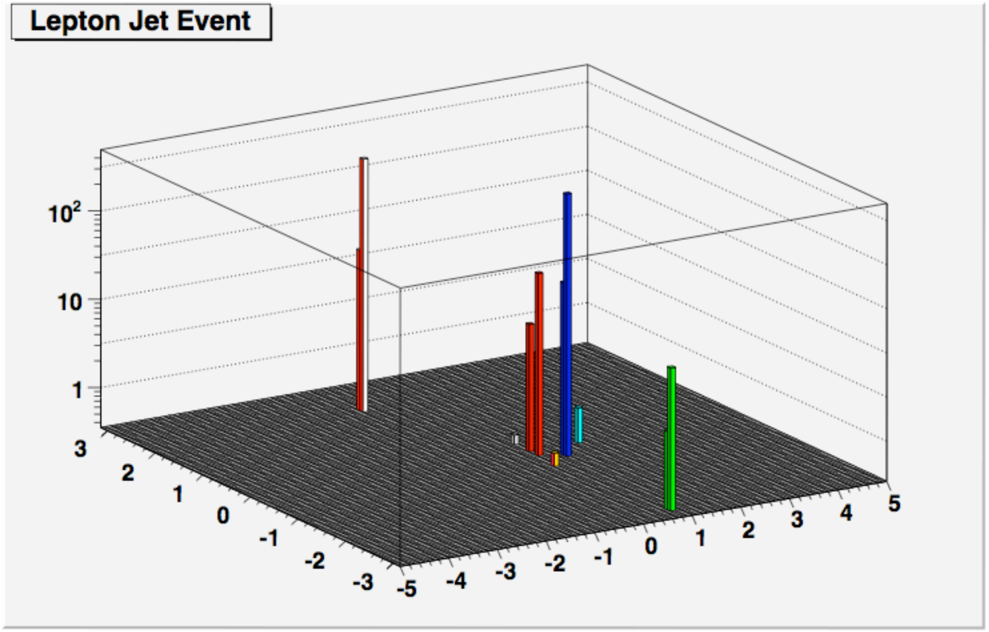
Dark Radiation

Dark Cascades and Lepton Jets



Part III

Lepton Jets



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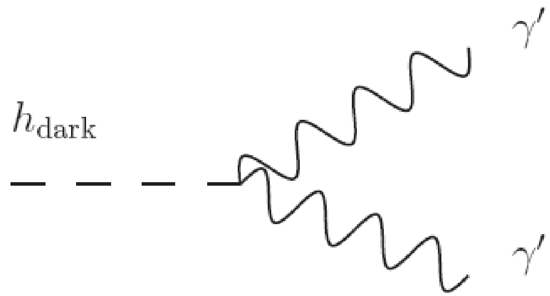

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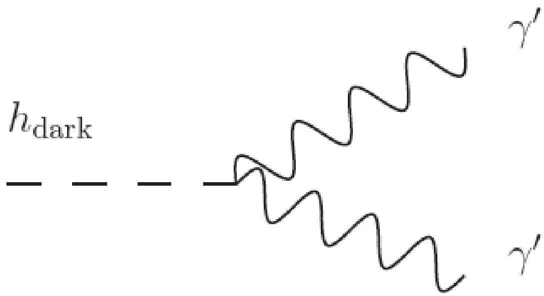

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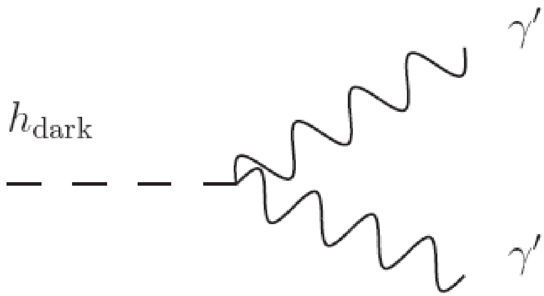

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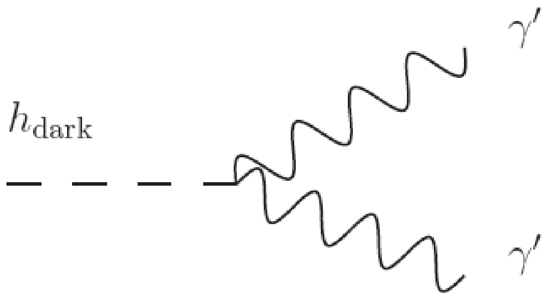

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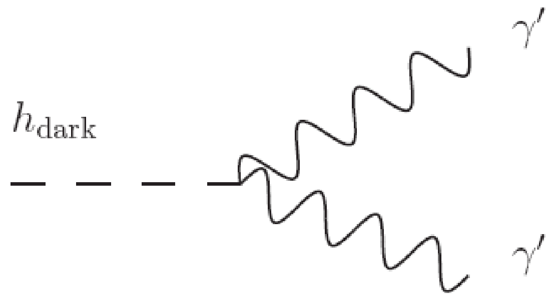

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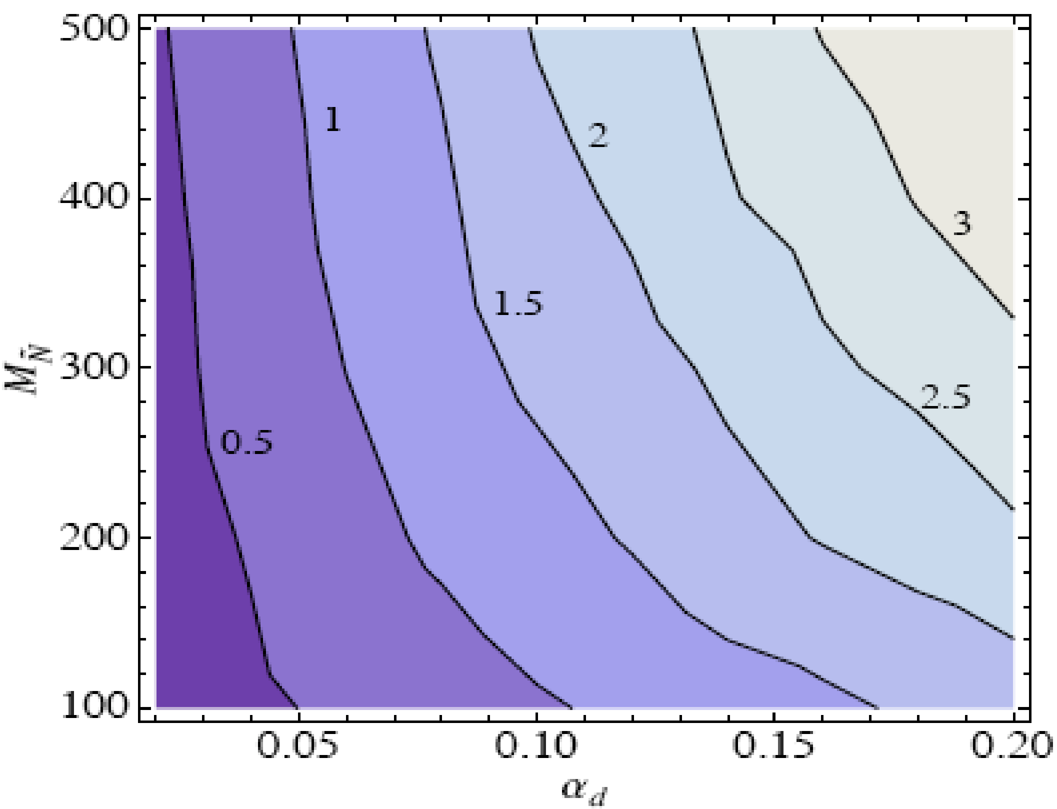
$m_h < m_b$ — Very long lived (missing E)

Dark Radiation

Since the dark state are extremely boosted, they will radiate dark gauge-bosons,

$$N_{\gamma'} \sim \frac{\alpha_d}{2\pi} \log\left(\frac{M_{\rm EW}^2}{M_{\rm dark}^2}\right)^2 \simeq 1.4\left(\frac{\alpha_d}{0.1}\right)$$



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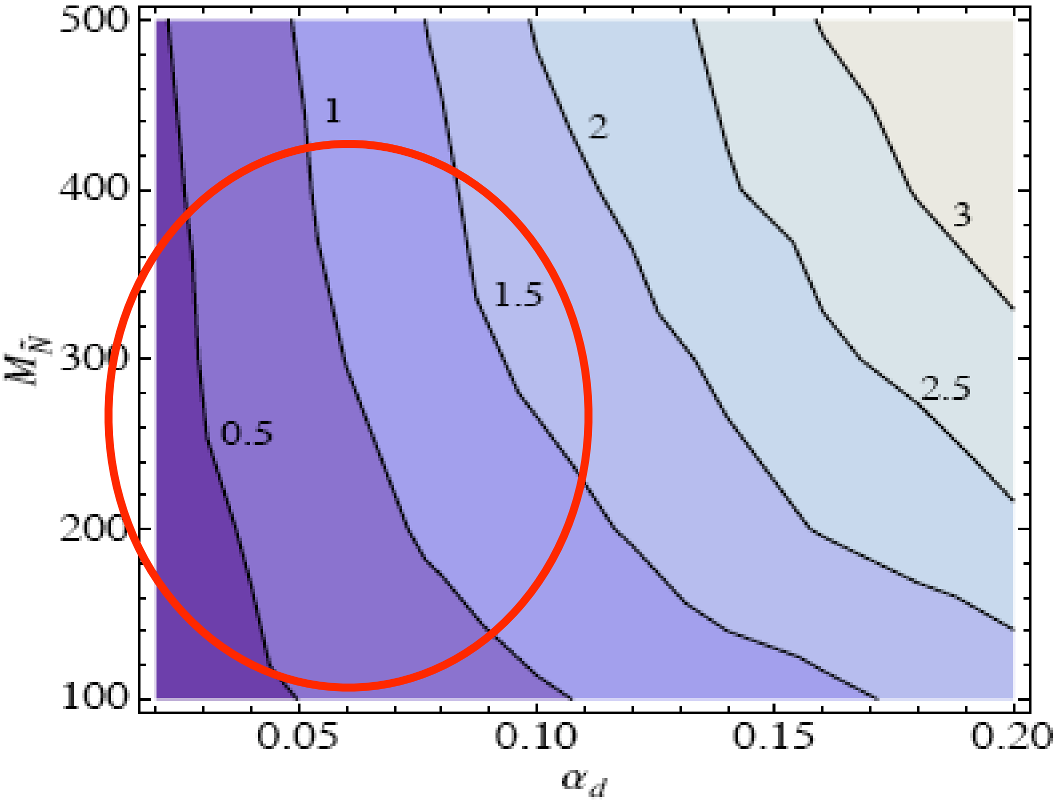

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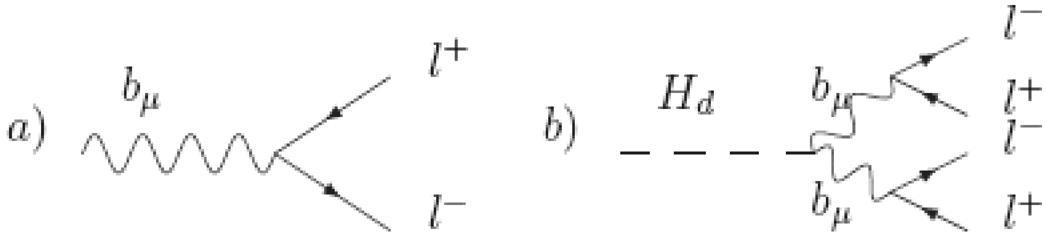

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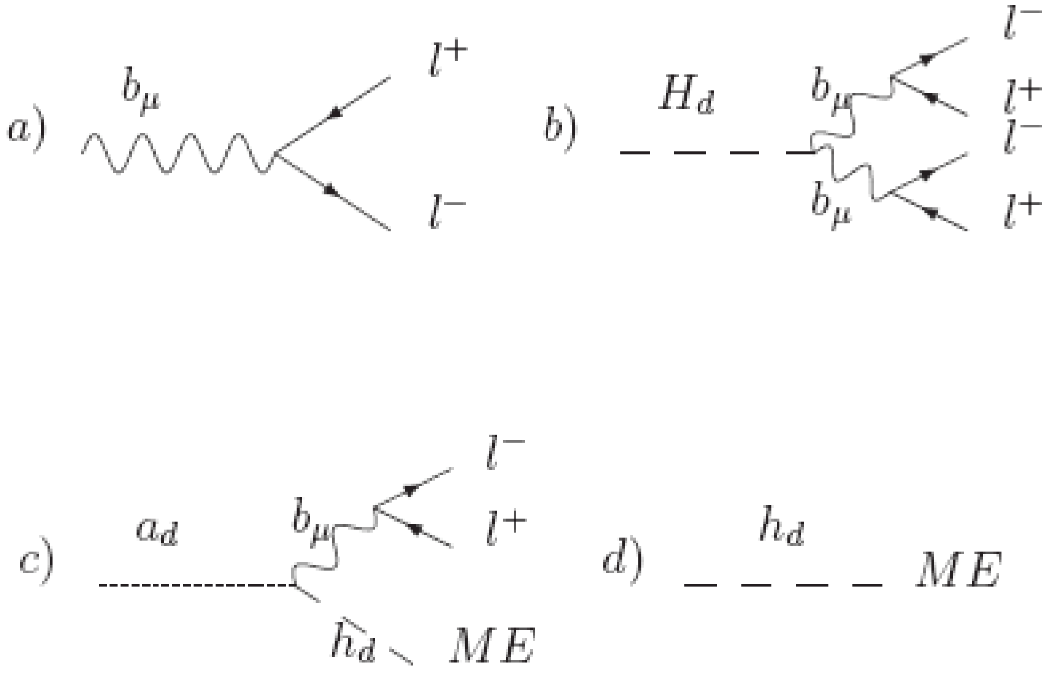

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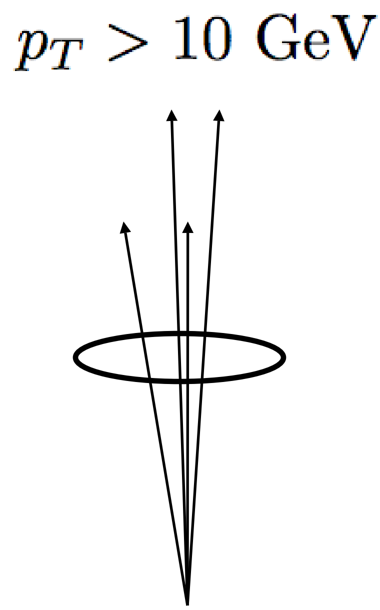

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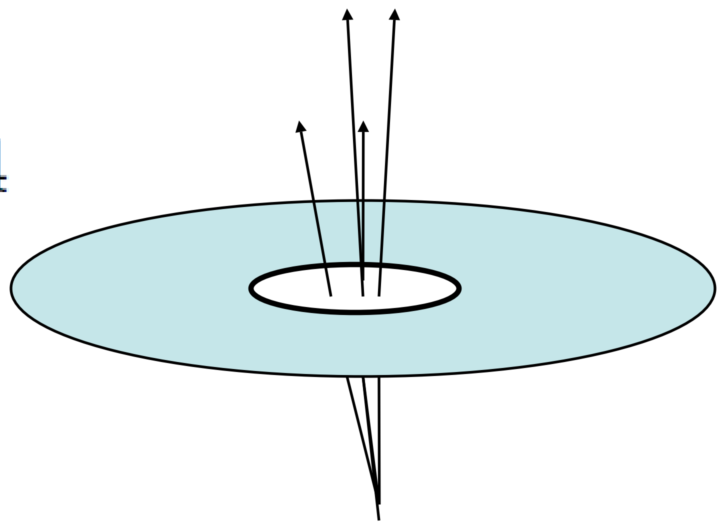

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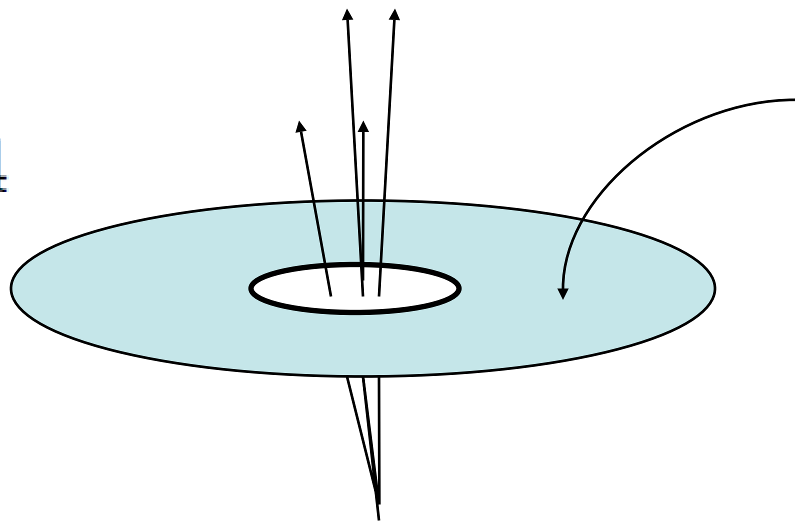
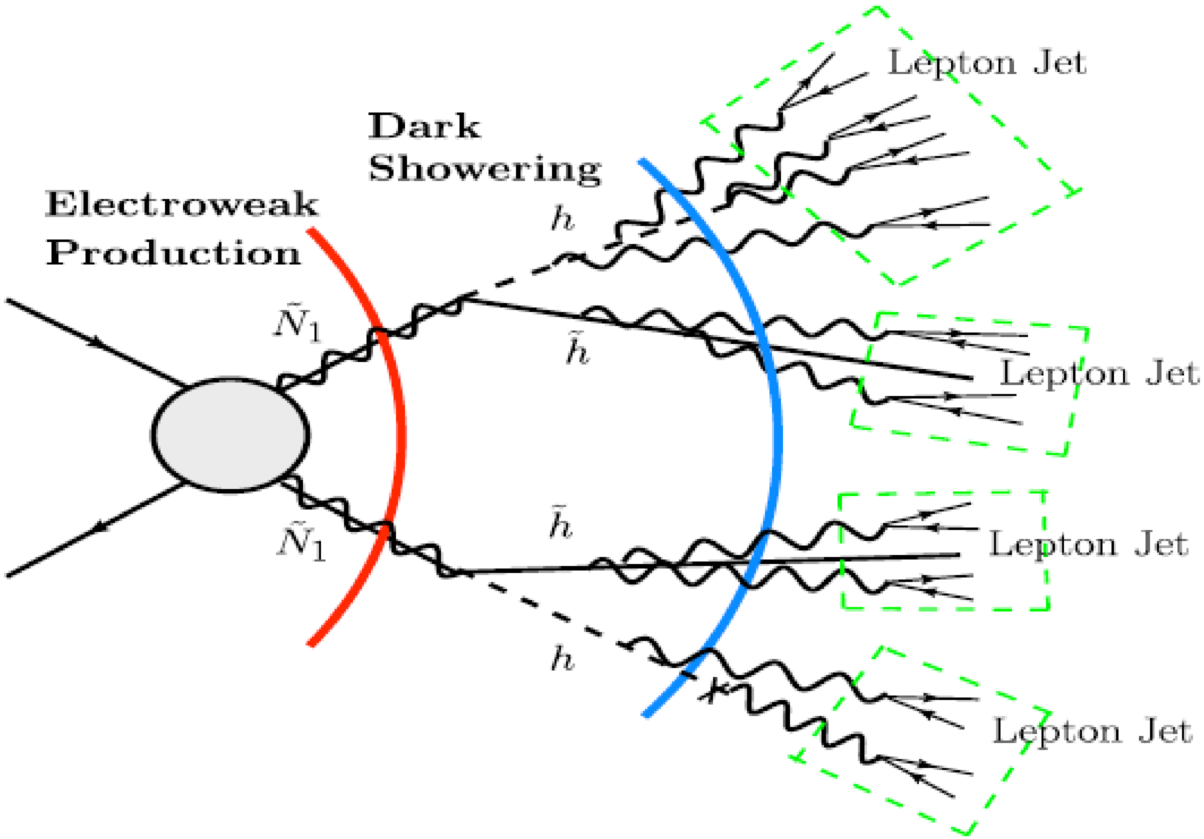


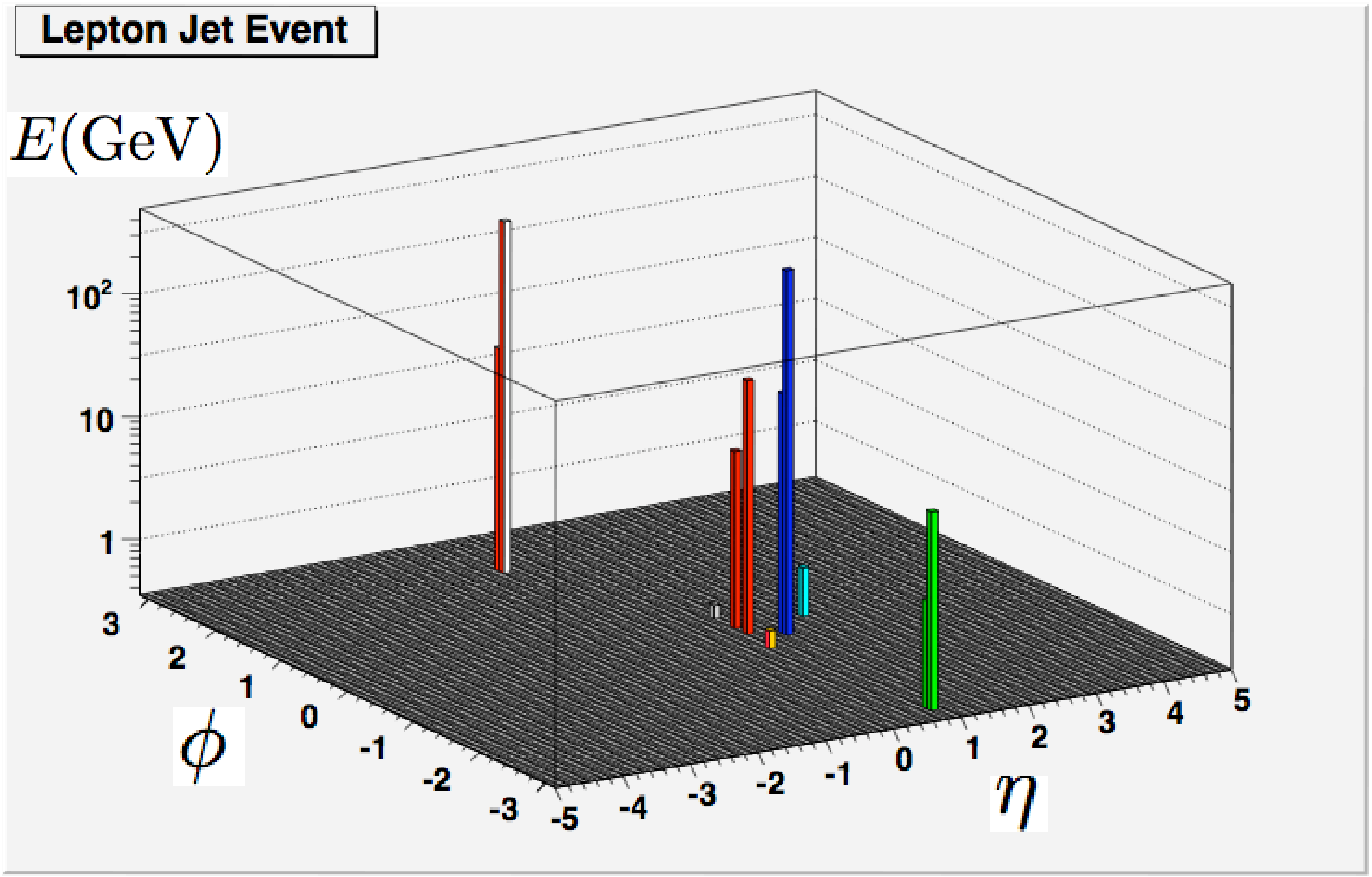
$$\sum p_T < 3 \text{ GeV}$$

Full Evolution



Lego Plots

For a 500 GeV LSP pair production, the event looks like:



Experimental Discovery

By defining lepton jets as a searchable object one can look for:

1) Lepton-jets + ME

2) Lepton-jets + QCD-jets

3) Lepton-jets + isolated leptons

While a resonance structure is probably present, since we don't know the mass, it may not very useful to implement mass-window cuts and etc.

Experimental Efforts

Several experimental groups are working on (designing) searches for lepton-jets

1) A. Haas and Y. Gershtein for D0 - Phys. Rev. Lett. 103, 061801 (2009), arXiv:0905:3381

2) B. Demirkoz and R. Moore for ATLAS - designing proper triggers for lepton jets.

3) K. Cranmer and the NYU group - lepton jet gun.

4) H. Lubatti and the Washington group - triggering on long lived neutral particles.

5) V. Halyo for CMS - searches for lepton jets.

6) Searches at BaBar - See all the local experts.

Sources of Lepton Jets

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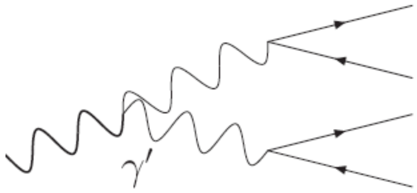
There are different possibilities for obtaining lepton-jets:



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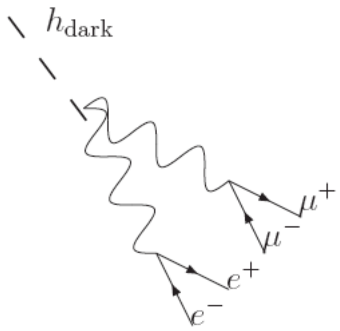

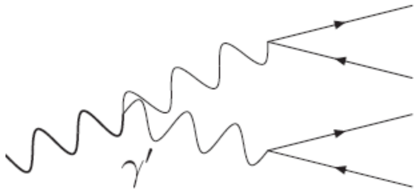

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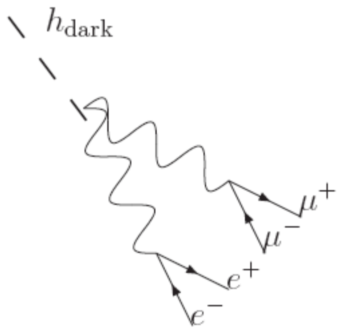

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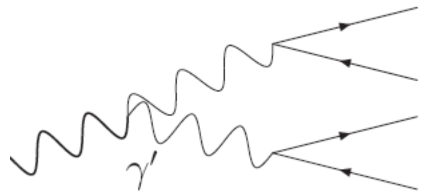

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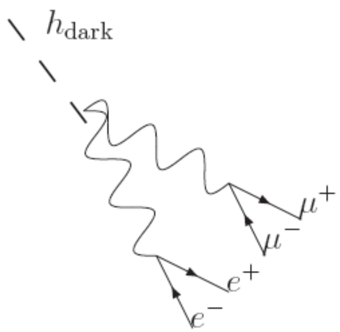

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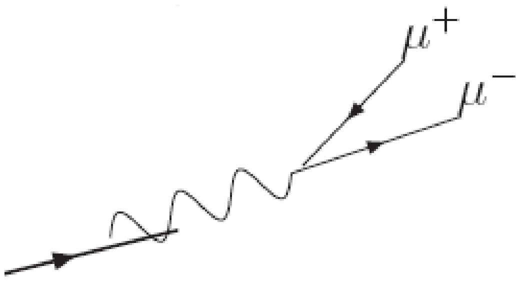

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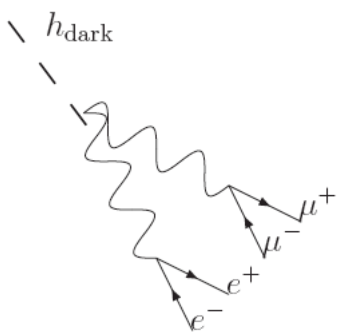

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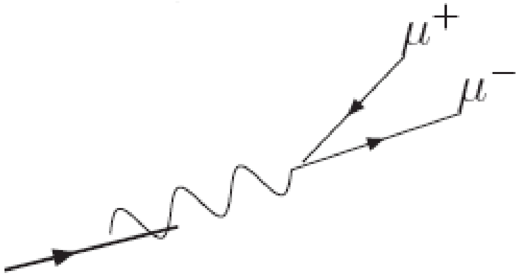

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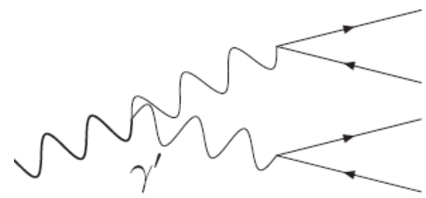

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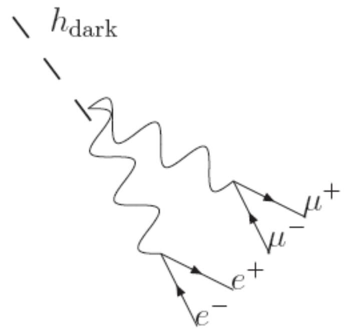

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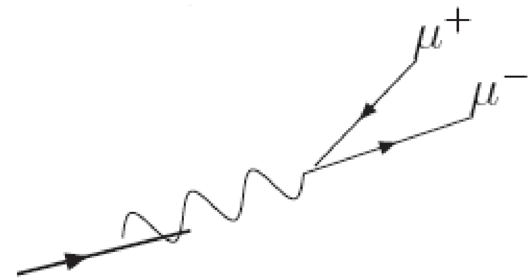

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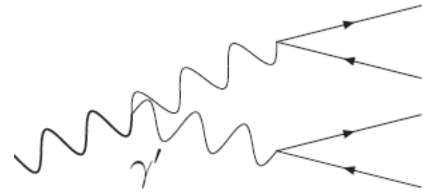

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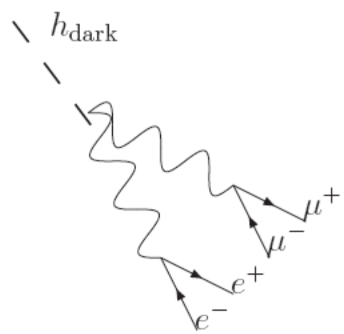

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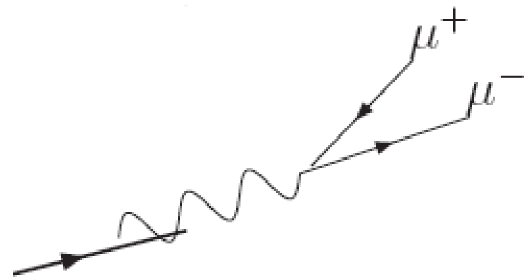

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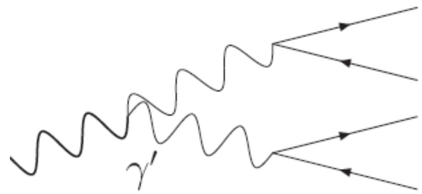
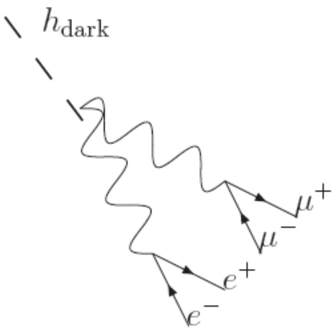
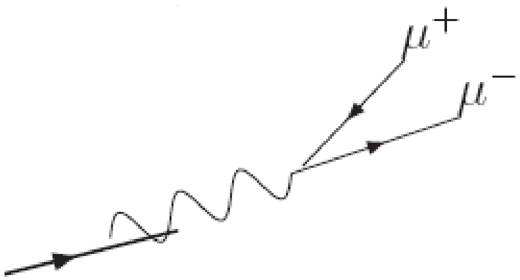


2) Dark higgs(es) decay



3) Dark radiation

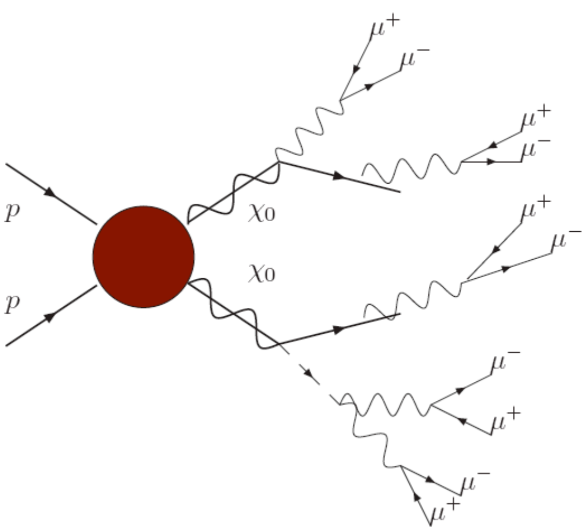


There are different ways of producing dark states:

1) Prompt dark photon

2) Rare Z decays

3) Susy cascades



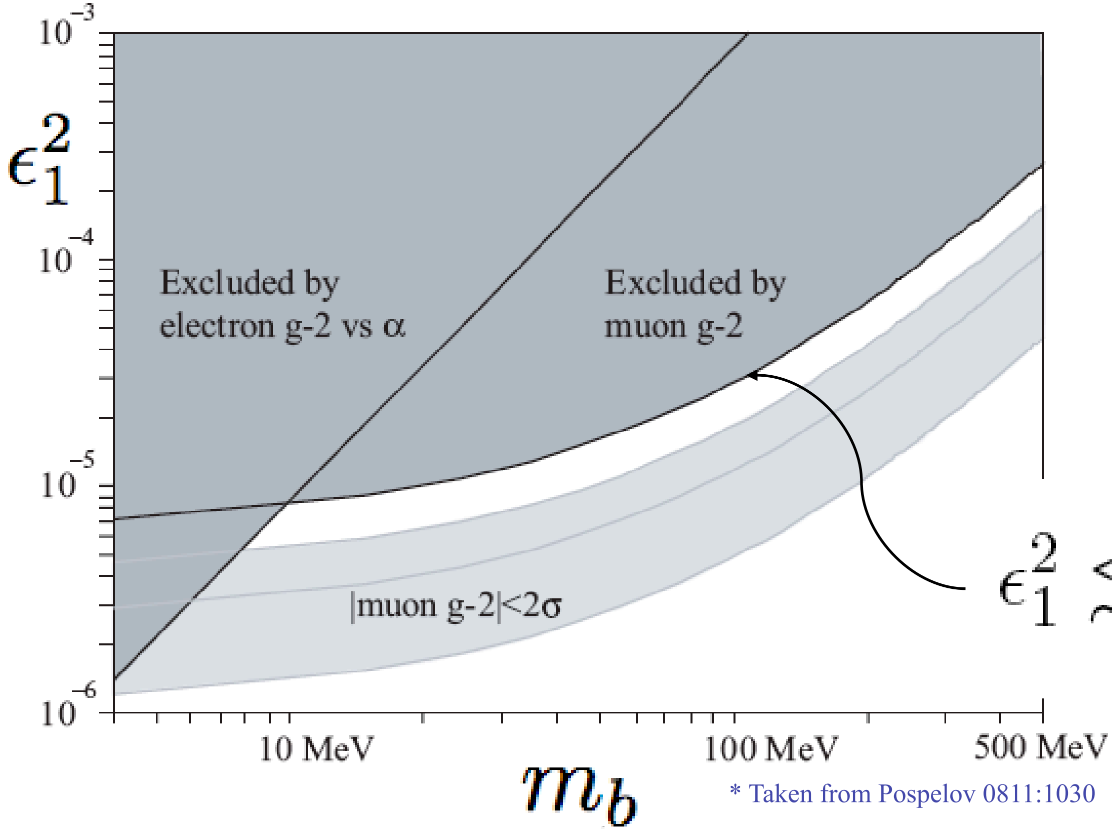
Thank You

Future Directions

- Searches at LEP and Tevatron.
- Searches at BaBar/Belle (see Essig, Schuster, and Toro) .
- Tune and modify triggers (see Demirkoz and Moore).
- Lepton-Jet observables?
- Other scenarios with similar signatures? (see Strassler and Zurek).

Limits on Kinetic Mixing

The kinetic mixing with the photon is bounded by low energy experiments, in particular the muonic g-2 ratio (Pospelov 0811:1030):



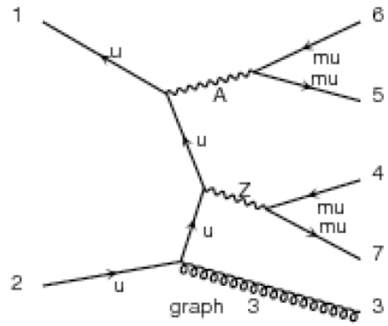
$$\epsilon_1^2 \lesssim 3 \times 10^{-5} \frac{m_b}{100 \text{ MeV}}$$

* Taken from Pospelov 0811:1030

Notice that this measurement does not bound ϵ_2

Standard Model Background

The SM can give 2 muon pairs recoiling against a jet and that is an irreducible background. Simulation with Madgraph suggest that this is not going to be a serious obstacle:



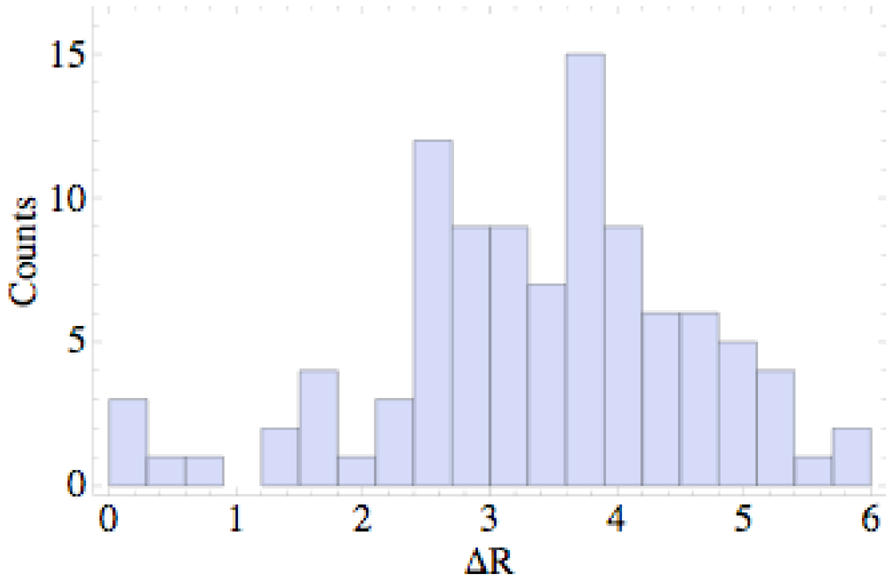
… and many more . . .

$$\sigma = 37 \text{ fb}$$

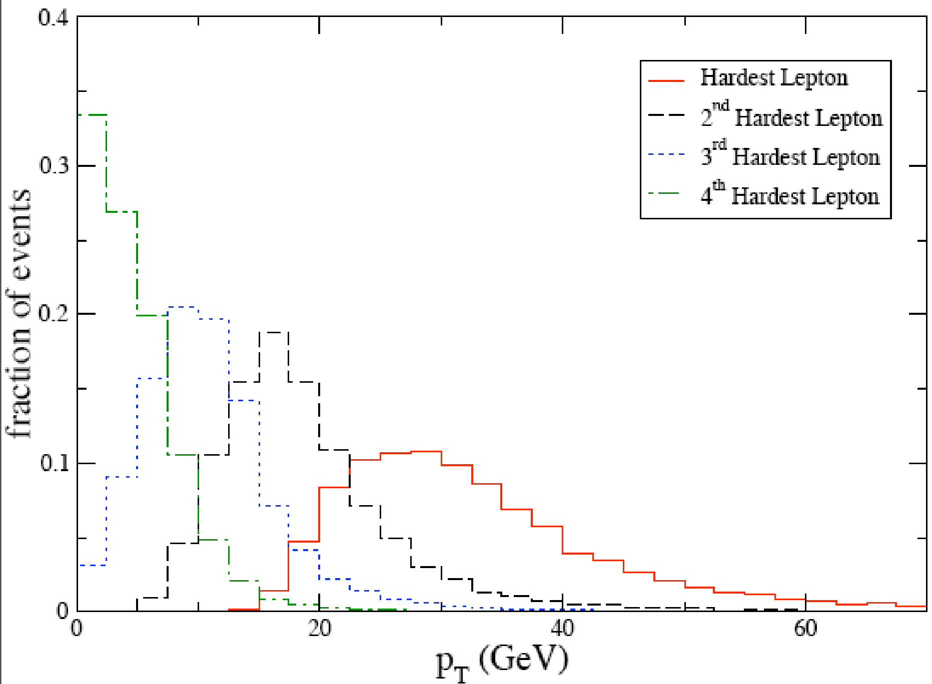
This can be reduced to **< 1 fb** by requiring:

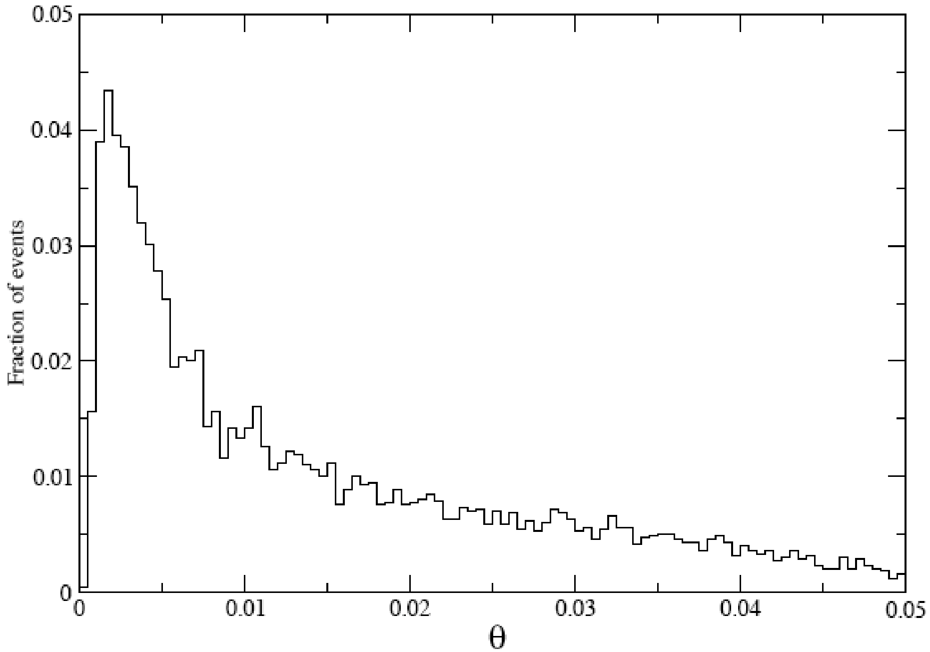
$\Delta R < 0.1$
pT > 3 GeV

For all 4 muons.



Detector Performance





Bilge Demirkoz and Roger Moore investigated ATLAS performance using the prompt dark photon production as a benchmark.

Bilge Demirkoz also implemented new triggers to help improve the efficiency associated with such events.

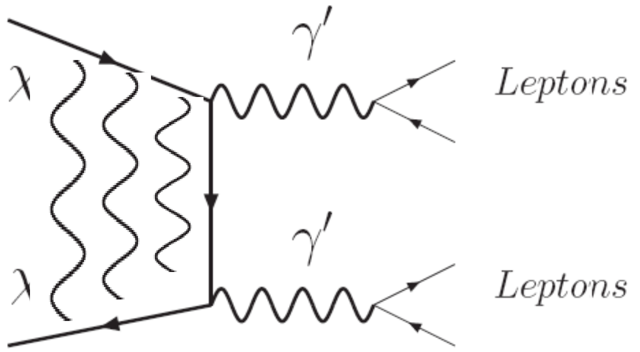
Lepton Jet Efficiency

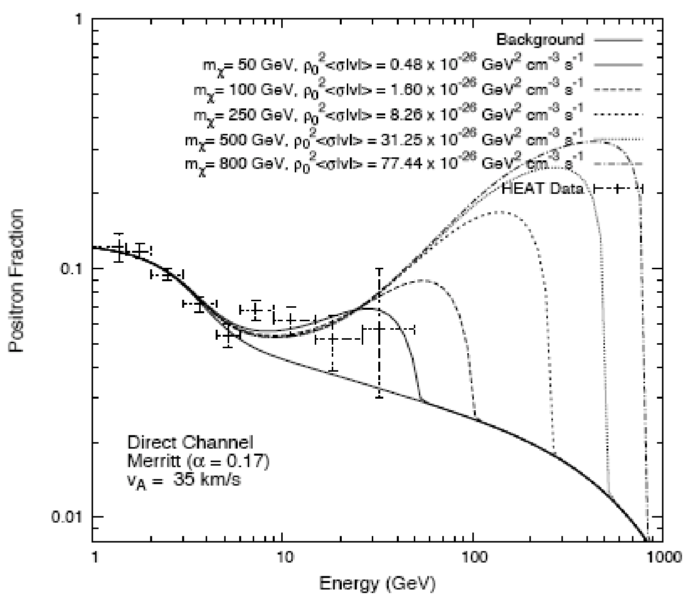
Lepton Jet Efficiencies						
	1 Lepton-Jet			2 Lepton-Jet		
$Br_{b\to\pi\pi}$	1/7	1/3	3/5	1/7	1/3	3/5
α_d						
0	0.49 (0.49)	0.47 (0.47)	0.31 (0.31)	0.28 (0.28)	0.14 (0.15)	0.05 (0.05)
0.01	0.47 (0.47)	0.44 (0.45)	0.31 (0.32)	0.3 (0.31)	0.16 (0.16)	0.04 (0.04)
0.03	0.43 (0.41)	0.47 (0.48)	0.3 (0.3)	0.27 (0.3)	0.14 (0.16)	0.04 (0.05)
0.1	0.43 (0.39)	0.41 (0.44)	0.29 (0.32)	0.23 (0.3)	0.13 (0.18)	0.05 (0.07)
0.3	0.38 (0.32)	0.34 (0.36)	0.25 (0.34)	0.16 (0.3)	0.11 (0.22)	0.05 (0.09)

Table 1: Clean lepton jet efficiencies for different values of the dark gauge-coupling and $Br(b \to \pi^+\pi^-)$. The neutralino mass was set to $\tilde{M} = 300$ GeV. For $\alpha_d = 0$ dark radiation was switched off. The number of lepton jets increases with α_d as radiation becomes more likely. The requirement for "clean" lepton jets, as described in the text, results in a decrease in efficiency with the growth of the branching ratio into pion. In brackets are efficiencies for the case where only hadronic isolation is required in the $0.1 < \Delta R < 0.4$ annulus.

Resolution of PAMELA

So dark matter annihilates to dark photons first. The dark photons then decay into leptons.





1) Protons are kinematically disallowed.

2) The leptons are direct products of the annihilations.

3) Sommerfeld enhancement of the cross-section due to light particle exchange.